Fish in Schools or Fish in Cans.

Evolutionary Thinking and Formalization

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Abstract: Gregory Bateson maintains that individual development and natural evolution follow the same principles; thus he parallels learning and evolution. I try to establish the precise mechanism in the case of human learning, by attributing to concepts the role of genes: We develop our thoughts conceptually through selection in the same way as living beings develop genetically. Thoughts thus evolve in our mind like fish in a cove, yielding concepts as the genetic material from which new thoughts arise. This puts thinking into contrast to talking, where we build sentences from words like buildings from bricks. Thus, while we represent concepts directly through words, thoughts have to be formulated into, and started from, sentences. Communication involves much choice, and thus chance; how come we relate so well, being so different? How do we share our thoughts if the world is so big? We have to care to keep our systems "small", to balance between "too big" and "too small". Otherwise we could not manage in man-made environments. This viewpoint yields consequences for learning and teaching; many of them are known, but may appear now in a new light. Communication is most risky with formal matters; formal concepts are needed to describe machines, and thus have to be developed through artificial breeding. This makes it difficult to do science in a responsible way. Computer scientists get into special trouble: Their task is, so it seems, to reduce any type of communication to electronics; with this megalomaniac goal how can their systems be small? How can they avoid canned fish? They have to "gestalt" computer assisted systems, that is, to design them in a way "as if humans mattered", by balancing between mere interpreting and mere constructing. For this task they need help from the outside: from philosophers, linguists, psychologists, educationers, sociologists. Does this turn (computer) science into utopia?

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Content

1.0 Evolution and Learning

He is careful of what he learns, because that is what he will know.
Annie Dillard "The Writing Life"

1.1 Writers, readers, and the world

With sentences the writer captures the world.

Wrong; because we change the world by writing. Not only that we put black marks on the tablet; that we enlarge someone's vision or consciousness thereby; that we ourselves learn by writing. No, not only that we extend the world. The world has been silently waiting for us to write. Now that we finally move the pen, finally the world moves. Something happens.

So with sentences the writer makes the world?

Wrong again; because the world makes us write. We only have to be ready. If we are badly prepared, we will write badly. If we are well prepared, and present, then we might get something on the paper that is right. We see something, and manage to put it into words. Other people hear, or smell, or taste, or touch, or feel something, and write it.

But now we are back to where we started: The writer describes the world. We have gone full circle. Which is why writing is impossible. A find that serves us well, because we separated the writer from her subject. The truer our story is, the less we will change anything; truth just repeats what there is. And the more we are out to be creative, the less we will relate to anybody; how could anybody understand what has not been before?

So let us start again, and put the writers and their world into one basket: Of course, we are in the world and change it while writing. And, of course, the world is in us and we bring it out through writing. Sounds intricate. But it does not work that way. Because we forgot someone important: the reader.

We cannot leave the readers out in front of the basket. How then were we to reach them? But we cannot possibly let them in either. Writers are allowed to be intimate with anything but the readers – lest they compromise themselves. Writers are supposed to finish their books or stories or poems, and then leave them on the table, and go away. And by come all the readers, and find the work, and are excited.

This is the difference between writing and seeing. When we see a tree, we form an image and are stuck with it for better or worse. But if we write about the tree, we implant the image into our reader's mind, and they get stuck with it. We are responsible for what we write. Of course, the readers are responsible, too. They can misread us, on bad purpose or with good intention, or by just being unprepared. But influenced they are in any case. From writing and reading a relationship emerges between reader and writer. And it is the writer who starts it. The writer breaks loose hell or paints heaven; and the reader follows the invitation.

We are responsible for everything we create. As long as we deal with a purely natural environment – as when we walk through the woods, or sleep in a meadow – nobody can question us about it. It is just natural, and we are part of it and may enjoy it or have to fight it. But when we take the car through the woods or cut the meadow with a scythe to sleep more comfortably, we are not as innocent. We are conscious about self-made things, otherwise we would not have made them. Whether we write a book or build a house, fabricate a tool or just fix spaghetti for dinner, we start with a blueprint, a plan, or at least an idea. And we conceptualize this being conscious about self-made things as "conscience", which hardens out as "self-consciousness", or self-esteem, in the long run.

So we may speculate that these three human faculties evolved together: creating artifacts, thinking and speaking about them, and being conscious about both and about ourselves.

1.2 Communication is symmetric

Why writers? What about painters, or musicians? What is so special about artists anyway? We all, whatever we do, try to communicate about whatever we do. Or for that matter, communicate through whatever we do; witness the cooking of a spaghetti dinner.

It is not generally acknowledged that communication is symmetric. The case of the spaghetti is particularly misleading here. You cook and I eat. This way you tell me that you like me, and I tell you that I like your spaghetti. Two different messages, statement and reply as in any conversation. Quite asymmetrical. Or are they? Would I take your cooking as a message, instead of as plain cooking, if I did not know that you anticipate my delight in spaghetti while you cook? And would I understand your message if I did not follow your activity step by step, preparing a complete though invisible dinner while you cook? Maybe I would have added a little more oregano to the sauce than you do, and I might wince when you break the pasta. Thus I do not precisely follow you, but go my own course. And by comparing the results on those points where we differ and changing my habits, I learn something. Next time I will try less spice. So there is a big difference between cooking and communicating through cooking. The communication is symmetric, though the cooking is not. This observation holds for the eating as well: You may not be hungry and just watch me eating; but if you would not get hungry mentally when you put the plate on the table, and if you would not scoop up the sauce with bread in your mind, my delight would be lost on you.

Watch yourself in a conversation. You are not just sitting there while I speak, like an empty barrel waiting to be filled with my words. If you did, you would have understood nothing when I am finished. Instead you talk while I am talking, supplying examples, contradicting violently, turning my sentences around to make them sound funny, answering all my rhetorical questions dutifully. You do this silently, but always on the verge of interrupting me, until you finally do interrupt me when the time is come. And me? You saw me talk all the time, but actually, likely without myself knowing it, I listened to you all the time as well. I saw you open your mouth, shrug, smile, move your body uneasily when I was about to hit, and in this way I sensed your answers and counterexamples, and doubled my efforts to convince you and my speed so as not to be interrupted.

So. If you watch it carefully, talking and listening are not opposites. You listen while you talk, and I talk while I listen, performing a battle or a ballet, a pas de deux in one. How could there be a battle if the swords did not cross with equal force at the same moment? How could there be a dance if the feet did not follow the same rhythm, be there music or not? The two persons in a conversation build a unity, namely the conversation. How else could they be “in” the conversation?

Now you see, you would-be writer, the predicament you are in. You want to communicate with your readers. But they are not present when you write; so how can you form a unity? If you did not want to communicate, you might as well go home and raise potatoes.

Or are you the type of person who puts their findings down on paper, and cares not who reads it? Supposedly scientists write that way. They find out the truth about a matter, write it up, and are satisfied. Whoever reads it will share the truth. Supposedly they even feel they behave responsibly that way. How can meeting the truth be wrong for anybody?

If you were to look closer – and I will make you do that later on – you would have to admit that, even in science, communication does not work that way. And definitely for you, the writer, the situation is more complicated. There is no truth do lay down and be certain about it. Rather for some reason you want to tell others how you see the world. The spaghetti story implies that it would not do to write down what you see. To write down what you see would be like cooking tribes for someone who has never had tribes. He might eat them or not, but surely would not get your message by just watching you prepare them.

1.3 Form and process

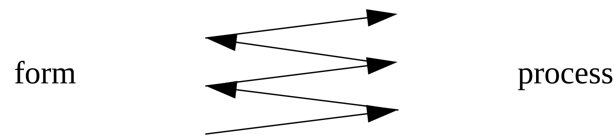
So what? Communicating through conversing or through cooking is easier than through writing a book, since writers do not see the audience react. But writers compensate through time. In a conversation I have to adjust to the audience while I speak; I do not get a second’s notice. But writers may take years to mill a sentence around; by then it should have the right form.

Why is the form so important? Writers *form*ulate their experience, bring it into a form from which the readers can extract a similar experience. Words is all the writers have. They want to convey their experience, their ideas about the world; so they had better find the formulations that carry these ideas.

But if words carry meaning as vessels carry content, what is this meaning? If it had an independent existence to which the readers were guided, how and where to should we imagine the readers guided? Without words the meaning spills like wine when the bottle is broken. And if the meaning were inherent in the words, how were the readers to take it out? Supposedly they are interested in the meaning, not in the words.

Let us listen to Gregory Bateson, the biologist, anthropologist, and psychiatrist, who all life long thought and wrote about communication. He never spoke about form and content. Content without form would not make sense, and form without content would be empty. Gregory Bateson used the pair *form and process* instead. Processes are what we experience: We do not see a tree, rather we see the tree move; or rarely, on a hot summer afternoon, we may see it not move, and wonder. We do not see the color ‘yellow’; rather we see the difference against the other colors around the yellow object by moving our eyes. We do not even see the cup on our desk if it does not invite us for coffee or raise our disgust by the stains it leaves on the papers, that is, if it does not move us. We feel the time go by, as the clock chimes or our heart beats. The sun goes up and down, and so does the moon. Stars twinkle. Children run, trip, and fall. When I realize what happened it is all over. I have to stop to notice, and I have to stop many times before I realize. It takes many heartbeats to feel my heart beat. And children do not see children run, before they move around themselves. So through repetition processes produce forms: habits, images and concepts, living organisms and dead matter. And processes run on given forms. We experience processes, but we cannot describe them. We can describe only forms, which we cannot experience.

It is through this zigzag of process and form that we learn, says Gregory Bateson. Through



many bodily and mental experiences we build up bodily and mental habits which allow new experiences which yield new notions and so on until we die. Bateson provides beautiful examples in and through his books : In his papers and lectures collected in “Steps to an Ecology of Mind” [1972] you see him struggle while these notions slowly evolve; in his late book “Mind and Nature” [1979] he narrates the theory and its story; after his death in “Angels Fear” [1987] you still see him at work with his daughter Catherine Bateson extending the theory to cover art and religion.

1.4 Forms from processes through experience

We experience an event through the way it affects us. When it is gone we want or fear it to come again, to repeat the experience, to keep it. So we wait until it comes again, and again, until we know how and when it comes, until we can make it come or stay away. Then the process has turned into a form. Through repeating experiences we build forms, which we use to secure even more repetitions. Thus we build forms to gain security.

There is nothing wrong with gaining security. Every living being builds forms all the time in order to stay alive. Since nonchanging things are dead, with living beings nothing is permanent. So in living beings forms are always decaying, giving way to new forms. Living beings grow this way: by replacing decaying forms by new ones.

In fact we need forms to experience anything in the first place. Forms are not the mere skeleton of our self through which the experiences flit like fish through the ribs of a sunken ship. Forms are molds into which processes pour to harden until we take them out. This is what we call ‘experience’. More precisely: We experience a process in the form of previous experiences to form a new experience. Depending on the perspective we may view ourselves as an unending sequence of processes rushing like waves onto the beach of our experience which we change thereby; or we may see ourselves as the majestic beach rushed on by the unruly waves, only slowly changed thereby.

Our first experiences come from our bodily needs and from people responding to them. Before birth our mother is always there, taking care of all our needs. Later we still depend on and long for her as well as for other people. We experience this in the form of many different feelings: we feel warm or cold, hungry or full, happy or sad, cared for or neglected. Basic, however, is the closeness of people and the urgency of needs, both of which stay, or come and go, persistently. This basic experience gives rise to the feeling of permanence that we rest our life and our sense of self on. When we later try to explore our self and find nothing there, we should not be surprised: Permanence means persistent recurrence, not constancy; and permanence grounds in others as much as in ourselves. If our needs were not strong enough – if we would not feel the hunger or the pain, say – we would be in danger on an animal level. But if the people we depend on behave in an unreliable or threatening way, our human self is weakened – up to the point of losing or never fully developing a personality.

So feelings are the first form of our experience. Objects, including bodies, are next. The baby gets hurt by a sharp edge or a clothespin, it watches its fingers move, it learns to throw its rattle, to crawl, to draw itself upright. Again objects can be persistent in form, properties, location, and orientation, and they are experienced in this way as recurrent, not as constant. And again the social dimension is dominant: A child left completely alone will not learn to play, and thus will not learn what objects are; and no child will ever walk that is not surrounded by walking people.

At the same time the first values are formed. If we call concepts what makes us deal coherently with feelings and with objects, values are meta-concepts: They arise from associating feelings with situations, thus are feelings run into form. Values are social concepts: From many experiences we know what our parents consider good or bad.

Finally with language the social relation is obvious. People accompany by talking whatever they do – or don't do – to us; only for a short while babies regard this a funny game. Soon they learn words as a key to almost everything.

1.5 Learning as zigzag between form and process

Let us again listen to Gregory Bateson. For him this zigzag movement between form and process is everywhere, on many different levels: A spinach plant opens a bud which, depending on the water and the sunshine the plant gets, grows into a bigger or smaller leaf, which in turn catches sunshine and moisture. Sea otters play following age old rules, and explore and develop their characters thereby. Children in class or patients in a ward compare the shell of a conch and the legs of a lobster, talk about the differences in symmetry, and learn about evolution that way. Giraffes and palm trees try to outwit each other by growing ever longer necks, thus enrichening our school books. Gregory Bateson calls this ever recurring pattern *learning*: An "organism" "shows" a certain "behavior", "experiences" a "reaction" of the "environment"; if this happens often enough, both the behavior and the reaction, thus the organism and the environment, will "change". The quotation marks indicate that the meaning of these words varies wildly with the situation considered. But learning it is, insists Bateson; therefore we can transfer what we know from one situation to another. Especially development of the individual and biological evolution follow the same principles. Both is learning, on a small scale and on a big scale, interacting.

Gregory Bateson is a biologist. Therefore he is mainly interested in evolution. When he considers individual learning he talks about giraffes rather than people. I am a computer scientist, teaching and learning at a university, with my family, with friends. Therefore I want to know: What happens when I transfer Bateson from the aquarium into the classroom? I invite you to sit down with me to unravel the precise analogy between human learning and evolution. What can we infer from evolutionary theory to the classroom situation? And conversely, can we get new ideas about evolution from what we know about learning and teaching? Where in heaven or hell is the evolutionary teacher? Or do we have wrong conceptions about our roles as teachers?

1.6 The analogy between evolution and learning

Any human being, body and mind, is subject to evolution. Although a new and powerful "invention" of the body the mind, being in the body, follows the same principles as the body. It is therefore helpful to imagine the human mind as an ecosystem, with thoughts as plants and animals. The ecosystem *mind* is part of the larger ecosystem *body*, which in turn is contained in even larger systems called 'family', say.

An event affecting the body is experienced as change in the mind. The sensation is thereby transformed into an individual *thought* "about the event". Thoughts thus arise from events in the body in the same way as new living beings come forth from events in an ecosystem: A new species evolves from those already present if the new sitution makes it possible. One is tempted to say that the changes suggested the species; but other species could have emerged, or none at all. To the same extent also the mind is free to make its experiences. A thought thus does not represent an event in the mind, it *is* the event continued on a different plane; or, more precisely: It is the change that the event produces in the ecosystem 'mind'.

Thoughts that are similar enough to combine fruitfully form a *subject*, as interbreeding beings form a population. As living beings pass their inherited characteristics on to the offspring through genetic code, so we use our conceptual bearings to pass the inherent characteristics of our thoughts on to the next idea. *Concepts* are thus thoughts condensed – blueprints, not building blocks, for new thoughts. As the characteristics of living beings do not correspond to single genes, but to complicatedly structured systems of genes, so single concepts mean nothing; only structures of concepts carry meaning. As newly acquired characteristics are not passed on in reproduction but have to survive in selection, so newly acquired ideas do not survive but through a long process of thinking and luck. Luck is needed wherever there is chance: As the genetic material may change randomly in reproduction through combination and mutation, so our conceptual bearings may change through the random combination af thoughts and through new ideas. The other source of chance, for living beings and thoughts alike, is random events from outside.

The mind experiences nothing but through the body. Therefore it not only forms concepts of other objects, but concepts pertaining to the body, too, and then concepts of the body and finally of the mind itself. We started with the mind as part of the body and the body as part of the mind, and found the body, the world, and even the mind, in the mind. The mind is home.

1.7 What are concepts?

Do you feel I have been oblivious with the terminology? To call ‘thoughts’ the processes that go on in the mind might pass. But concepts as genes? Gregory Bateson, thinking about learning in general, did not use the word ‘concept’. In his book “Mind and Nature” [1979] he talks about forming “names” for experiences, sometimes “notions”; in “Angels Fear” [Bateson & Bateson 1987] the relevant notion is “mental images”. I like the word *concept* better. When we think hard about a situation, trying again and again to clarify our thoughts, to make them stable and communicable, to make them fit the world – then slowly the thoughts crystallize into concepts. And again from the concepts new thoughts arise, another generation.This is exactly the process of “calibration” about which Bateson talks, the zigzag between process and form. Thoughts are processes. Thoughts happen, they are alive, and swift, and gone. Concepts are forms. Concepts form from thoughts, they are stable, and thus the form for new thoughts. Only on a grander time scale concepts change, too, as the genes change trough evolution. – Bateson does not speak about thoughts either. To him processes are outside events, directly affecting the mind.

Some philosophers will find this use of ‘concept’ outrageous. The word is so heavy with history that it were better not touched. Sure enough, all philosophical schools agree that concepts – whether they be classes of objects or eternal ideas, whether they are real or derived or plainly imagined – always form unities. In contrast in my picture concepts are distributed. Not only that we all know fish, and thus have this concept in common; but also ‘fish’ is in all my thoughts about fish, and so it is in yours. Actually, ‘fish’ is in all our thoughts about subjects that are, however remotely, related to fish. Wouldn’t we think differently about tonight’s dinner if we liked fish better or less, even when we know that there will be chicken soup with rice? So. Imagine the concept ‘fish’ not as an exceptionally big or beautiful fish nor as the class of all fish nor as a vague schema generating fish out of nowhere nor as the bones left over after you picked away all differences among fish.

Imagine a school of fish. You are standing at a rocky shore in Southern Greece peering into the calm water. You ought to have the sun in your back. First you see nothing. Then you see speckles of the rock, and maybe of yourself bent over on the rock, dance on the waves. Then you see images of clouds and sea gulls moving overhead beneath you. Finally when you are calm you see fish. There is a whole school moving through the water, swiftly, gently, their translucent bodies flashing when they turn and catch the sun. Hold your breath. Hold it. This is your concept of fish, moving with your thoughts.

Don’t fall. Don’t fall back into the old misconception that you see all the fish you have ever met or heard or thought of. Look hard. You don’t see any fish, neither real nor imagined. You see fish as they could appear in your thoughts tonight. As no thought is like another, all these fish are a little different in form or color, seen from different perspectives, thought of in different thoughts, moving differently, but always in formation. Some seem more prominent than the rest; but then they sink and blur away from sight while others rise and take their place. Some seem to lead; but then the school turns, and others take over.

The picture may be beautiful, but it is still misleading. In reality you cannot see these concept-fish. “You cannot see fish”, Annie Dillard laments in her “Pilgrim at Tinker Creek” [1974]. She is a poet and a literary critic, living at times in a cabin near Tinker Creek in Virginia. “The very act of trying to see fish makes them almost impossible to see.” Only with the sun in her back can she see into the water within the blue shadow of her body. The fish, however, see the shadow loom, and vanish. “Occasionally by waiting still on a bridge or by sneaking smoothly into the shadow of a bankside tree, I see fish slowly materialize in the shallows, one by one, swimming around and around in a silent circle, each one washed in a blue like the sky’s and all as tapered as tears.” If she thus succeeds, however, it is with real fish. We cannot see concepts, we can merely use them in our thoughts. Remember: We cannot experience forms, we can only describe them. Concepts are forms, thoughts are processes. If we try to grasp the concepts we will only disperse the thoughts.

When you managed to imagine the concept ‘fish’ as a school of fish, try another concept. Try eels, or sea horses. Be careful with sea robins. Annie Dillard once happened to see a whole crowd of shark milling in the surf in a feeding frency, as she reports in “Teaching a Stone to Talk” [1982]. I cannot do sharks.

Now combine the different kinds. Look around, scan deeper. Fish are everywhere. Schools move about in all directions. They cross through each other when you combine them in a thought, some forming a single line for a moment, or jabbing at each other and darting off, or even attacking each other, and then disengage and move on. Beware of seals now.

Finally walk over to the next cove to watch someone else’s fish. By and large you will find the same kinds there, moving through each other similarly. They look a little different, as sun and wind change and the rocks reflect the lights differently. You may have taken a couple of your own fish along – some big and strong ones which you can call by name – and let them go now. They will vanish, or create a confusion, or interbreed with the natives. When you look closer you realize that the fish are actually somewhat different here: Rocks and plants are different and thus provide a different environment. You also see schools moving freely around the headlands from cove to cove, or coming from the open sea, or falling from heaven as flying fish. At night monster fish rise from the depths.

1.8 Enaction, image schemata, and p-prims

Fish in schools are beautiful to look at, but what they tell us sounds technical. Biologism revived. Mental Darwinism. The picture becomes livelier, I promise, when we look at some practical consequences the theory offers for epistemology, learning and teaching, system design, writing, and religion. Before we can do that I have to spell out the theory in more detail. Spelling is hard on everybody. So to make the going easier I will relate the outlines sketched so far to three detailed pictures I got a glimpse on here at Berkeley. More or less all of them concern the mind and the body united.

In their recent book “The Embodied Mind – Cognitive Science and Human Experience” Francisco Varela, Evan Thompson, and Eleanor Rosch [1991] set out from Buddhist meditation. Meditating we first experience our restlessness. Our thoughts flit hither and thither, not like tranquil fish, but rather like mad birds. When we quiet down, we experience “emptiness” or “ungroundedness”. I like the second term better, since emptiness smacks after nothingness. I cannot experience nothing. (Am I not meditating deeply enough?) There is no self to hold onto, indeed there are no objects, no other people, no world to step on. Anything is related to everything, there is no firm ground. When we accept this, we really might experience emptiness: Everything vanishes, we fall off the world. In Western thought Buddhism is often understood as leading thus into nowhere, and there might be Buddist traditions where this seems to be the goal. The three authors, however, emerge with another perspective which they call ‘enaction’ or ‘codependent arising’. If all things depend on each other, they will not fall off the world, since there is no world to fall off. Rather they arise codependently, supporting each other, enacting the world. If we realize this, we no longer need a world to step onto, rather we enact the world. We become quiet, but not withdrawn. We deal with the world wherever we are, whoever we are. We stop minding, and thus become aware and mindful. We stop caring for ourselves, and thus become strong to care for everything, although there is no caring self left.

Fish in their cove are like that. There is no superfish that stands for the school, or stands out in front of the school. There is no self that stands for the cove, or represents the cove. There is just the body of water, but nobody behind it. Don’t miss it: The water may be pure and nourishing, or foul. The fish may be healthy or stinking with cancerous growths. The headlends lead into other coves with fish swimming back and forth. Each cove may be beautiful or ugly. How can it be that we are responsible for ourselves and for others, if there are no selves? How can we talk and think about each other, if there is no concept of self or other? These are hard questions. I promise to deal with them, but I cannot now. I just wanted to give what seems to me a different perspective on the same issue. If you do not believe in perspectives, just close one eye.

Still another perspective can be taken from Mark Johnson’s book “The Body in the Mind” [1987]. Here the author presents the philosophical foundations for his and George Lakoff’s theory of the importance of metaphor in language. They started with a joint book “Metaphors We Live By” [1980] and continued separately in the above book and in Lakoff’s “Women, Fire, and Dangerous Things” [1987], drawing on research on categorization and concept formation as reported for example in the book “Cognition and Categorization” by Eleanor Rosch and Barbara Lloyd [1978]. According to the theory the words that are basic in our language get their meaning directly from bodily experiences. We know ‘in’ and ‘out’, since we know how to get in and out. We know ‘warm’ and ‘cold’, since warmth and cold are basic experiences from the first day on. We know ‘to run’ and ‘to fall’, since as children we loved to run and hated to fall, doing both a lot. Since we know these words, we understand what it means if someone falls asleep or from grace (although there is no actual falling), or if someone runs into trouble or into a cold reception (although she might sit or stand, and there is no opening to get into). Through many examples the authors show how most of our language gets its meaning from metaphors, often in long chains and complicated constructions.

How does the business start, in which way do the basic words get their meaning? The mind starts in the body, Mark Johnson says in “The Body in the Mind”. The body itself provides the mechanism, which Johnson calls ‘image schemata’. Whenever we encounter a situation where some things are in something and others are out, the “container schema” flashes up and provides us with a rich conceptual structure concerning ‘in’ and ‘out’. The structure is rich because our experience is. There is no independent mind, observing the world and describing the experience. There is no independent world, impressing itself on the mind. Rather the mind evolves experiencing the world through its body. And the body evolves enabled by the mind to transform sensations into experiences. Mind and body depend on each other in a circular way.

Fish circle like that. A cove without fish would be dead. And fish without cove are impossible. But once there is a cove with fish, new fish come in continuously. Some might be weak or strange to the environment, and will be eaten or lost. Others might be healthy and meet a school of their kind; they will be accepted and reproduce. In reproduction strong characteristics like having a horizontal tail fin will be inherited invariably, whereas weaker ones like color or form will be less certain, and vary or vanish more easily. Analogously in thinking the concepts that we have built up from childhood and which are thus strong in much of our thought – for example, spatial concepts arising from body movement – are picked up in a flash from sensation, whereas weaker ones that are more specialized and thus occur rarely, will have a harder time to get through. Thus I liken Mark Johnson’s image schemata to “universally valid” gene combinations which occur everywhere and are strong in reproduction. Objects with an inside and an outside, with a hull to contain things and an opening to put things in and get things out, are common and useful, our own body being the nearest example. For this reason they are recognized and fancied easily. Metaphors then might be mechanisms that enable weak concept structures to hold on to stronger ones to get carried through, as certain gene structures cling to stronger ones, riding piggyback into eternity. Metaphors are genetic mimicry.

The third picture is from Andrea diSessa’s writings on how we learn scientific, especially physical, concepts, and how we should thus teach them. Just to confront students with an axiomatic theory is the worst thing we can do. How shall they understand the laws moving objects obey, if they do not know the basic concepts involved? They are no empty glasses into which the teacher pours knowledge in the form of definitions, laws, and theorems. Rather they have, possibly wild and inconsistent, basic ideas about the subject; diSessa calls these notions “phenomenological primitives (p-prims for short)”. If we want the students to learn we better start from their p-prims instead of handing them our own. I am quoting from his paper “Phenomenology and the Evolution of Intuition” [1983]. Evolution? Sure enough, p-prims are the genetic material of primitive populations in the agitated sea of our mind. The water is not at all clear, but you can sense the native fish swim about. If you pour the strange fish of your own theory in between them, fight and confusion will result; at best they will ignore each other. Why not – by feeding the fish you like and scaring away others, and by adding fish that are familiar enough to interbreed – change the environment gradually?

By now you might be confused by so much fish. Didn’t I introduce the fish picture to talk about concepts distributed in our thoughts? Now fish seem to be thoughts, ideas, statements. Right. I like fish, so I am using them ambiguously to talk about either, concepts or thoughts. Once the idea of thinking as evolution has become clear, we may speak about fish carrying their genes or about genes representing their fish, interchangeably.

This should not blur the important distinction between thoughts and concepts. Whatever concepts you want to teach, you cannot transmit them; all you can do is talk about them and hope them to grow. Teaching means breeding, not selling.

Still this is rather vague. The picture seems to fit, but does it provide anything new? We will have to look closer, figure out the analogy in more detail. I will do this first in a formal way, not to obscure the picture by rash conclusions. Thereafter I will discuss learning and teaching more generally. I will deal specifically with formal concepts later, in the third part of this report.

1.9 The picture in greater detail

For a primitive account of evolution I will use the picture of animals interbreeding in populations living in an ecological niche; their characteristic properties are inherited through systems of genes. – For a primitive account of conceptual learning I will use the picture of thoughts intercoursing in themes occurring in a mind; their characteristic ideas are preserved through systems of concepts.

Animals preserve themselves through reproduction within their species, not through mumification. In this fashion they pass their characteristics on to their offspring, and die. Cycling between birth and death the ecosystem is perpetuated, albeit changing thereby. – We preserve our thoughts by occupying them under some theme, not by storing them in memory. In this fashion we pass our ideas on to new thoughts, forgetting the old ones. Through thoughts arising, engaging themselves, and evaporating our mind is perpetuated, albeit changing thereby.

In reproduction animals cannot pass on to their offspring their acquired characteristics, but only those coded genetically. Properties do not correspond to single genes, but to combinations; genes are stored in complicated structures. From the genes transmitted new animals grow according to fixed rules. – In thinking we cannot pass on to new thoughts the ideas just acquired, but only those fixed in concepts we already master. Ideas do not correspond to single concepts, but to combinations; concepts are kept (but where?) in complicated structures. From the concepts transmitted new thoughts arise, according to which rules?

Genes are not found directly in the world, only in living beings. We can touch animals, but we cannot touch the genes. Genes are highly distributed: Each animal contains a complete set of genes, in an individual combination. The set is characteristic for the kind, the individual version determines the individual. In reproduction all genes of the species are involved. – Concepts are not found directly in the mind, only in thoughts. We can grasp thoughts, but we cannot grasp the concepts. Concepts are highly distributed: Each thought contains a complete set of concepts, in an individual way. The set is characteristic for the human being, the combination determines the thought in question. In thinking all concepts pertaining to the subject are involved.

Genes do not change directly through experience of the individual, otherwise no properties could be preserved over time. In reproduction the gene system may change through mutation and combination in a random way. Animals from different species will not reproduce. Animals of the same species, but from different ecosystems will reproduce only if the genetic material is similar enough. – Concepts do not change directly through our tending a thought, otherwise no ideas could be memorized over time. In engaging our thoughts in a theme our conceptual bearings may change spontaneously and through random combination. Thoughts on different themes will not match. If people think and talk about a theme, new ideas will arise only if their conceptual bearings are similar enough.

Living beings change from inside and outside events. They could not live without constantly changing through interaction. We view a totality of potentially interacting living beings and things as a unity, and call it ‘ecosystem’. Outside events have no effect on the ecosystem, except through impacts on its members. – Thoughts change from meeting other thoughts (; we know nothing of the inner life of thoughts). We could not live as mental beings without thoughts thus constantly changing through interaction. We view a totality of potentially interacting thoughts and feelings as a unity, and call it ‘mind’. Outside events have no effect on the mind, except through sensations affecting our thoughts and feelings and values.

An ecosystem changes trough selection: Those individuals that interact better with the environment – giving and taking – are stronger in persisting and reproducing, thus have a greater chance to override others in time. In this way the gene pool slowly changes; experience thus filtered is inherited. – Our mind changes through selective thinking. Those thoughts that interact better with other thoughts – giving and taking – run stronger in memory and are more productive, thus have a greater chance to override others in time. In this way our conceptual bearings slowly change; ideas thus filtered become established as concepts.

Since everything the individual learned dies with it, evolutionary changes seem difficult and slow. Ecosystems may change fast nevertheless: As every animal carries a complete set of genes, a new characteristic latent in the genes may suddenly erupt and alter the system. – Since everything new in a thought vanishes with the passing thought, mental changes seem difficult and slow. We may change our mind fast nevertheless: As every thought carries a complete set of concepts, a new idea latent in the concepts may suddenly erupt and alter our mind.

1.10 Learning about the world

Being a foreigner here I have to learn new words. I read Annie Dillard’s “The Writing Life” [1989] and stumble over the word ‘tether’. This spiky greyish fish is new to my cove. Never seen before. It’s not in our English-German pocket dictionary either. Vague associations with ‘feather’ and ‘tester’ do not work; they do not fare well with the other fish in Annie Dillard’s sentence. So I turn over to the American Heritage which I love.

(Only it's so slow to handle.) "To restrict or bind with or as with a tether" gives me a first idea; I am familiar with most of these fishes, except of course the last one. A tether is "1. A rope, chain, or halter for an animal, allowing it a short radius to move about in. 2. The range or scope of one's resources or abilities," says the next entry. This gives enough live backdrop to let the new fish swim freely. While I watch it move, still a bit awkwardly, it multiplies miraculously, soon forming a school dancing with the other schools. I actually have seen people play tetherball, I realize. I put the new fishes back into the sentence where the original fish came from, and now some of them fit. The sentence makes sense. I will have to use the word three times a day for some time to nourish it, until it is well on its own. (This is an advice Jan Wojcik once gave me.) Or rather, now that I wrote about it, that won't be necessary. 'To tether' is firmly established in my cove, and with it, alphabetically next to it, 'teth' which had been about to die out without me noticing.

To understand better what is going on, especially to extirpate the embarrassing qualifier 'miraculously' in the last paragraph, let me translate the colorful fish story into the evolutionary setting suggested by the Bateson analogy. Now concepts are genes, and fish represent thoughts. The new fish in my cove is now Annie Dillard's sentence, which is a fish alright but for his greenish color that I have never seen on a fish of that kind. To perpetuate that characteristic I have to breed it with other fish. Actually a dictionary is a highly technical way to go about it: I extract the gene and see how it works in other fish I know. Gene technology. A more natural way would be to read on, hoping to find the word again on later pages; to listen to people who might use it; to try the word in conversation and watch people react. Through breeding in this way the characteristic might appear in other fish, the gene would go stronger, not at all miraculously, and I would get to know the word.

You might say: The situation of learning is well investigated, and I know the phenomena; what does the fish picture tell me? It gives us a theory, I would retort: We can explain known phenomena coherently, and predict new ones. If learning a concept works like breeding a characteristic, this has a lot of consequences: We learn by "resonating", not by taking over. Therefore we learn nothing but through carefully and thoroughly handling the concepts involved. Concepts that "interfere" well with our knowledge are assimilated fast; others slower or not at all. This explains what Carl Friedrich von Weizsäcker states, namely that messages do not carry information if they are either old hats (taken easily into the cove, but leaving no effect) or never-heard-ofs (not acceptable into the cove, thus again leaving no effect). Only messages in the middle range mean something to us; but it takes time to take them in.

The fish picture also can help us to access Gregory Bateson's zigzag ladder of form and process, leaving it less rigid at the same time. The ladder and the word 'calibration' seem to imply that we learn only through repetition: New forms arise from alternating between form and process repeatedly until we are done. For many years I had "I will work quietly" written fifteen times on a nicely ruled piece of yellow paper by our eldest boy in his best first-grader handwriting, winking at me from my office wall. I doubt whether it made him work any quieter – or me for that matter. Now that I take the rungs of the ladder as generations, I see more clearly why the teacher did not succeed: Fifteen identical lines do not yield one new generation. The other extreme, a single jump, won't do either. One cannot understand a concept from reading a definition. It took me many days to grasp what the

Great East Bay Fire really meant. I saw it happen; but it had to work its way slowly down into my guts.

Still it is only an analogy, you might insist; concepts are not really fish. Then I would refer you back to the book I mentioned earlier, “The Embodied Mind” by Francisco Varela, Evan Thompson, and Eleanor Rosch. If I experience the world and the mind as evolving together, neither of them yielding a foundation for the other, how then could either of them be more real than the other? My mind grew up together with my body, figuratively through history and literally through my life. My thoughts do not represent the world, they are the world, my world, continued on a different plane. I can think about fish, since in my mind the concepts behave exactly as the fish “out there”. Words carry meaning, because it grew with my encounters with the world, not because of some established relation; how then could I distinguish between fish and ‘fish’? Now you will laugh, and remind me that I could not eat the words, or could I? Well, I sure like fish, but could I eat it if I did not know the concept? Have you ever put a piece of leather into your mouth, thinking it to be fish? Now tell me, what did you chew for a moment before you spit it out? Neither leather nor fish, I bet; but maybe ‘leather and fish’. This new experience makes you spit. Therefore I am right not to distinguish between concepts and objects as long as everything runs normally. Only if my fish differs from what my ‘fish’ demands I will start watching both. But which of them is thereby more real?

If you are too much used to accept nothing as real that cannot be experienced through our senses (mind excluded), then you might locate concepts in the immune system. Francisco Varela has found that it works like a “second brain”, and indeed, is strongly interlinked with our nervous system. Since I do not know more about these findings, especially no publications, I cannot speculate further.

The Bateson ladder of form and process is ungrounded. Indeed, it has no beginning: How could processes run if not in forms, and how could forms arise if not from processes? It has no end either: How could the evolutionary process stop? Thus the ladder is evolving continuously, is a process; what is its evolving form? Take any part of the ladder, and you have a form: an intermediate result, nothing but one step in a ladder of higher order. And conversely: Any rung in the ladder is itself a ladder of lower order. Only that by going up or down you run into circles; so ‘higher’ and ‘lower’ does not make much sense. Any process going on somewhere influences so many other processes that you get around the world quickly. Someone once figured that one needs at most six steps (if I remember correctly) to get from one person to any other if one takes ‘well acquainted personally’ or ‘having shook hands before’ as a step. The number might be even smaller if you take ‘coexisting in the same ecosystem’ to go from one species to another, or similarly ‘coexisting in the same mind’ for concepts.

But communication, you will shout; if your fish evolve in your mind and mine in mine, how can we talk about them? So we are finally back to where we started: the spaghetti. You would rather have dessert? Write fifteen times: “ I will eat my spaghetti quietly.” We may have p-prims for dessert. Andrea diSessa, however, is dealing with formal concepts like ‘mass’ and ‘force’, not natural ones like ‘fish’ or ‘leather’. They behave quite differently, more like fish in cans than like live fish. There will be a lot more to chew on before we get to them.

1.11 Communication

Remember the story of the spaghetti dinner in the early section on communication? There I tried to convince you that communication, as in a conversation, is symmetric: When you want to understand what I say, you are not listening passively; rather you are actively, although in a more or less hidden way, retelling my story in parallel through commenting, objecting, reformulating, and mapping out your own ideas of where to go further. And I will not succeed in making you listen if I do not listen carefully to whatever I can catch of your version of the story. Like in a ballet, when the ballerina leads in a pas de deux, her partner does not step onto her toes to be carried around, but follows her movement with his body; and if she would not feel him move, it would not be a pas de deux, but two singles dancing. Like two lovers...

Like two coves communicating. In a conversation as it is normally understood you would send fish over from your cove, and if I liked them I would send some in return, and so on. But it is not as simple. First you better select the fish you want to send, carefully: They should fit to what you have in mind to say; they should be strong enough to make the journey and to arrive at the right cove; and they should be fit to survive in the new environment. This is the classical sender-receiver model of communication: You select the fish and the channel, and I receive what you sent, maybe somewhat distorted. In the symmetric model this is only half the story, since now I become active, too. Your fish cannot survive in my cove if they do not feed and discharge, fight and make friends with the native, and especially if they do not interbreed. Thoughts do not live that long, maybe one seventh of a second. To survive they have to reproduce, and change and be changed thereby. Thus I do not “receive” your fish the moment they arrive, but only after they are really settled in. You would have a hard time recognizing them by then, so badly or beautifully will they have changed. I might not recognize my cove either, for the same reason. So when you tell me a story I do not simply take in what you say. Rather from what I hear you say I enact my own story. This way I understand you. So when you want to see what my understanding made of your story, you have to reconstruct it from my reactions as described above.

Neither of us can see into the cove of the other nor can we carry fish over and dump it (as I suggested in the first account of the fish picture). This is the consequence of the theory that I find most hard to accept: that we cannot put our ideas into other minds directly. We can only send them there and hope that they evolve as we want it. And yet, don’t we all know it? Teachers and students, children and parents, lovers among each other, enemies against each other – we experience this difficulty all the time. We complain about it. Use it as an excuse. “Nonsense! You just don’t want to understand me.”

I intentionally used the word ‘enact’ above. I took it from the book “The Embodied Mind” mentioned earlier where the authors explain the interdepency of world and mind as “enaction”. We are not enacting the world on the stage of our mind, nor is our mind enacting a play of imitation on the stage of the world; rather mind and world enact the play together. Of course, when the world and the mind are at stage, there is no separate stage left for them to play on. Especially there is no director of the theater. I cannot follow, however, the next step of the authors that there is no world or mind either. I am too deeply involved in the acts going on in my cove, and too fascinated by the cruel and fascinating stories I hear from others, to give all this up. I must admit that in the biological half of the analogy between evolution and learning the cove is not self-conscious; it cannot give itself up, or refuse to do so. Or so it seems.

Niklas Luhmann in his book “Soziale Systeme” [1984] is more radical in this respect. To him a system consists of events. Thus there are three systems involved in a communication: the two mental systems, which I call ‘minds’ or ‘coves’, and the social system of interactions between the two, which I call ‘communication between two people’. To Luhmann ‘me’ and ‘you’ are but convenient terms to speak about the experiences that come up persistently during a conversation. This radical view helps to disperse the traditional view of people as containing minds, and of minds as containing ideas which are exchanged in a conversation like pingpong balls. Still I prefer to stick to people.

Understanding then arises in three stages in a conversation. We start by emitting sounds and moving our bodies. The first stage is that we take these physical interactions as messages. Remember the spaghetti: You cook and I eat; if either of us fails to see the meaning involved, there will be no message, just food. The next stage arises when what you say makes sense to me. If I am used to feed on grubs and beetles, I will have no idea what you are scrambling about in your kitchen, even if I get from your smiles that you want to do me something good. At a final stage I understand what you mean. You know that I like spaghetti and that I am hungry; and I get the meaning. Or you know that I hate spaghetti and you cook them anyway; and I get the meaning. In real life situations are rarely extreme – otherwise we would not call them thus – ; understanding is therefore not a matter of yes-or-no, but of more-or-less. Communication is risky; you never quite know. How else could it be so exciting.

In the fish cove picture the three stages are easily identified, and then better understood. The physical interaction is the exchange of fish. At the first stage there is the question whether I take your fish as fish, or as waves or cloud patterns. Second I might accept your fish into my cove, but they do not fit any population there, and thus get driven away or eaten. At the crucial third stage the evolutionary story enacted by your fish in my cove might or might not lead to the results you had in mind. There is no joint stage nor director.

There are people, however, in my view. If they really want to understand each other, they will try to infer as much as they can from the messages how well the two plays relate, and make them come out similar or at least produce similar results.

Actually I learned the first half of the conversation piece from my wife. She is much faster and better in talking than I am, and so often I felt interrupted, and we would quarrel. One day she said: “You would do the same to me if you could. You sit there and open your mouth and try to interrupt, only you don’t succeed.” I was puzzled, but after a long discussion I had to admit that she was right, and then we found out why. You might interrupt me here by saying that we invented an elaborate theory just to make me look better. But there is the other half, that the talker listens, which complements my beginning. After that, too, became clear I recovered it from Heinrich von Kleist's beautiful little piece "Über die allmähliche Verfertigung der Gedanken beim Reden" [18??] (On the gradual manufacturing of thoughts while talking). This is how he sets out with the story: "When you want to know something that you cannot find out by meditation, then I ask you, my dear thoughtful friend, to talk about it to the next-best acquaintance. It must not at all be an ingenious fellow; also I do not mean to say you should ask him about it. No! You should tell him first." (My translation)

So far I have not distinguished between thinking and talking. Both thoughts and statements are fish. Thoughts swim in our cove, and statements are sent around. There is, however, an important difference in their status. Thoughts swim on their own, we cannot do much about them. Our power and our responsibility lies in the interaction. We select what we want to say and how; and we can, by directing our attention and our feelings, work on understanding what others say. For this reason communication is so important for mental development. In learning thoughts develop in our mind internally through combination and spontaneous ideas, under the influence of thoughts arising from experience, and especially from communication. Talking without thinking is stupid, but thinking without talking – at least to an imagined partner – is fruitless: it does not lead far. I wonder what logicians and fans of Artificial Intelligence might say on that point. The difference between thinking and talking will be the main theme in the second part of this report.

1.12 Bits and pieces for an ecology of learning

"Thoughts are contagious." So one says. And they are, if people are not immunized. Take any situation where people are afflicted by the same experiences: an audience bored by a lecturer, a gang marching through the streets in high spirits, a population tortured by poverty or dictatorship for too long. Throw in the right sentence, let loose the right incidence, and they all will explode with the same ideas, the same actions. As if in a convention of the Association of Pollen-Allergic People mischieviously you open a container with birch pollen. Then again there are vaccinations against some diseases; after some mild infection our body will grow anti-bodies. If you want your daughter to grow up a devoted Christian, let her know enough about other religions and anti-religions so she wont fall prey to the first missionary who comes against her. Not those people are saints who do not know sin; rather they are clear-sighted enough to spot the danger early so as not to let it spread. To tamper with diseases, however, through either infecting or vaccinating people easily works the wrong way. Most people who hate mathematics have been immunized or made allergic in an early age either by family members who hated the subject, or by their mathematics teachers who (presumably) did not.

We saw the Great East Bay Fire on Sunday, October 20, 1991. We were terrified and felt helpless, as did everybody who watched. On Monday morning we read all the newspaper, and went on working as usual. There was nothing we could do. It was not before three or four days later that the fire broke out in my mind. In the middle of quiet writing some story would pop up and unscroll itself. I would wake up at night. I had simply not worked out the experience: We had called and written to close friends and relatives about the fire, but we do not know enough people here to really talk about it; we had never been in any of those burnt houses, and hardly in the region; we are not really in the Berkeley way of life.

So the impressions did not attach to anything real in my mind, could not father or mother children and grandchildren, and get eased out that way. They got encased and stored away, but leaked out through hidden ecological pathways, until they contaminated my mind. The newspaper carried similar stories about fire victims, who were dramatically more affected, in the same time scale. Presumably the experience gets enshrined in them by shock, until it finally explodes like a disease gone haywire.

Our memory is not a store, but a cove swarming with fish. We cannot enter thoughts (leave alone "facts") as in a register and leave them there for later use. We rethink them and work with them constantly, have them change in a changing environment. Most of this does not happen consciously, but deep down; through some incident the thoughts, or what became of them, resurface. The cove is not a container from which we take, and into which we put, fish after our delight. There is a sunlit surface to which fish constantly rise, and sink away again. We see only the fish near the surface, and there only those to which we direct our attention; for others we have to wait to come up again. The cove is varied. There are shallow parts where we can see to the ground; there are unfathomable depths where fish hardly ever go or come from; there are niches and confined areas sealed off by rock barriers or seaweed or dangerous animals where it takes high spirits and strong determination and great effort to go to. Thus it is that we attend only one thought at a time, but others are waiting close by, and then there are layers and regions of greater and greater depth and distance. But everywhere fish are alive and reproduce and evolve, although in different speed. The "unconscious" is not an ice chest, rather the deeper and farer part of the cove.

The notion of a store where one puts something in and takes it out later unchanged is central to computer science. A classical computer is nothing but a huge store ("memory") and one, or relatively few, processing units ("thinking") that retrieve data from the store, process them, and store them back. In contrast a mind has no store, all its parts are constantly active and change, although we concentrate at one part at a time only. How could people ever think that one could simulate the mind on a computer, let alone that the brain were a computer? I have written more on that in my papers "People's bearings on computers" [1989] and "Turn towards imagination - On theory building in computer science" [1990]. Today many researchers in Artificial Intelligence do not believe anymore that computers could exhibit intelligence, but so-called neural networks could. Like computers, however, networks are grounded: One starts with some network constructed from basic elements, which is then modified and possibly extended through "learning" (correction or self-correction according to experiments with given input-output relations). In contrast the fish cove mind is ungrounded, as we saw, like any living being. There are other problems with the basic assumptions in Artificial Intelligence – for example, their negligence of the unconsciousness which, however deep or shallow we construe it, plays an important role in our thinking. I will come back to the theme later when I deal with formal concepts.

We know a lot about biological evolution. What would we get when via the analogy we applied it to individual learning? How exactly, for example, do thoughts change when we combine them? Logic does not help here. In Logic one works with the traditional pair of form and content, and looks for "logical conclusions", which follow from the form independent of the content. Such steps are uninteresting, since by definition nothing new appears. Thoughts are processes. They combine with regard to the concepts involved, forms of quite another kind. Such steps can be creative, namely if new concepts are created thereby, or old ones changed in a surprising way. But again, how does this happen? (Note that I talk here about thinking, not about change by experience, especially by communication.) And finally, how do new thoughts arise from concepts? Does here ontogeny follow phylogeny, the development of the individual the development of the species, as in biology? What are mental species? Themes, as I suggested above? Which thoughts reproduce, and which do not? Do thoughts have sex, and thus, a sex? Or are there other categories, like “women, fire, and dangerous things”? Are there “lower” kinds of thoughts that reproduce “asexually”, that is, nonconceptually? Are these emotional thoughts, where we desire or despise, but do not judge and categorise? We need an ecology of thinking and learning.

The picture of evolution I used, and thus the resulting picture of learning, is crude. The authors of “The Embodied Mind” quoted before would pound me on my head for some formulations. They want to overcome the traditional view of evolution where the species lives in a pregiven environment in which the fittest individuals survive. Instead they describe evolution as an interdependent development: One cannot separately specify individual and environment, and then have them interact; they define each other, and cannot meaningfully be considered singly. I took this concept of ungroundedness from them, and made it central to my theory, too. The finer picture, however, is still to be painted. I will mention only one major consequence now: Teaching and learning are symmetric, teacher and student are codependent. Trivially, without the one the other could not be; but I mean it deeper: I cannot teach the same lecture twice, give a talk a second time; I cannot even read a manuscript to an audience. My wife and Heinrich von Kleist knew this before me: If I don’t learn while I teach, I don’t teach; if I do not engage with the audience, they cannot hear me. And conversely: If I don’t struggle with my teacher, at least mentally, while I listen, I don’t learn.

“How about radio and TV?” you will ask. “If you don’t expect us to learn from your writing, why do you write?” Did I trap myself? I started with the problem of the symmetry of the reader and the writer, and ended up to prove – in writing – that the writer cannot reach the reader. Poor job. Yes, but not quite. With the ideas developed so far we cannot solve the problem. The writer does not directly communicate with the reader, she cannot send her fish around and wait for the return gift. She has to can her fish and sell them. Now, dear reader, how will you revive the fish from the can, and make them swim?

2.0 Communication and small systems

It is hard to desecrate a grove and change your mind.
Annie Dillard "Teaching a Stone to Talk"

2.1 What are representations?

According to the American Heritage dictionary 'to represent' means 'to bring back' or 'to stand for', normally when symbols are employed. Examples are: All of 7, 111, and VII represent the same number; in the genetic code each three-letter word of amino acids represents a certain protein; this genus is represented by seven species. The synonyms 'to mean' and 'to signify' are more general; 'to denote' requires clearly defined meanings.

Thoughts have meanings. They are events we experienced, continued on another plane, namely in the mind. Thus thoughts are, like events, processes. But whereas the event, once happened, does not change, especially cannot be undone, the thought lives on, combines with other, matching, thoughts: What might have happened, instead or afterwards; what similar experiences we had had earlier or heard of later; what we might do if that event happened again; what we might do to make it happen, or prevent it from happening, again. What we remember is never quite what happened. Thus the thoughts resulting from an experience "mean" the experience only in a loose sense. They allow us to work with the experience, to work it out; but they do not "represent" it, since they change.

With concepts it is different. Relative to thoughts concepts are fixed, unchanging. Like the things they represent. Or to state it more precisely and more helpfully: Concepts change as much as the things they represent do. Or rather, and then it becomes almost a tautology: Concepts change as much as our knowledge of the things does. It is a tautology, since our knowledge rests in our concepts. Genes change as much as the species they "represent" does. Now the tautology is obvious.

Or is it? Earlier I quoted the authors of "The Embodied Mind" as struggling with the notion of codependence. The species cannot be defined independently from the environment, both evolve together. Therefore the genes are not independent either; but the environment does not evolve genetically, so there is nothing to match the genes. Thus all we can say is that the genes do not specify the species in itself, but along with it the mechanisms by which the members cope with the environment. Or, to put it less physically: In the genes lies the range of possibilities which the individual has in a given environment; these include the many ways to alter the environment. The genes mark a range of relations between animal and the world around, including the relations between the genes (as part of the animal) and its suroundings. Thus the common (mathematical) notion of representation is too neat and too narrow here. With a representation one sets up an exact (often one-to-one) correspondence between the things to be represented and the representing things, neglecting everything outside. In genetics, since there is no strict inside and outside, the "coded version" (Bateson) contains the references to possible interlocutors as well. Similarly concepts represent, or code, our knowledge (the body of thought around a given theme) only in this wide sense. The above statement "Concepts change as much as our knowledge of the things does" is not a tautology; it expresses that our knowledge develops evolutionary.

2.2 Representations in communication

Representations appear only with communication. What you say "matches" more or less something I have in mind – that is, the incoming fish are similar enough to interbreed. Incoming and native fish are never identical, together they "stand for" something ideal, they "mean" the same thing. This ability to digest "information", to match "pattern", becomes a habit. "Information is the pattern that connects", says Gregory Bateson. We are used to the experience that different descriptions work for the same thing; we create different descriptions for our own sake, even when we are not talking, or are talking to ourselves in front of the blackbord or a piece of paper or the computer. Different descriptions give a richer view, a more colorful picture. We are used to switch back and forth between different representations, trying to use the one that fits best the present situation.

Concepts are forms, whereas thoughts are processes. Thoughts are not built up from concepts, rather concepts are blueprints that combine to produce new thoughts. Sentences, however, are built up from words as building are from bricks; and words stand for concepts, indeed "represent" concepts in language. So in which sense could sentences stand for thoughts?

It is as if language, which seems so natural to us, is invented against nature. Thoughts evolve naturally from concepts. Sentences do not evolve. They are not meant to evolve. They change their meaning together with the words they are made up from, as we will see more precisely later; but as a structure built from words they stand unalterable. You can repeat a statement as you said it or differently, but you cannot – except metaphorically – take it back. Whereas thoughts evolve "conceptually", sentences do not grow, they are fabricated. Language is man-made.

So are tools. Tools do not grow like cabbages. They are made for certain purposes. Even when the purposes cannot be fully described, since nature is involved and always new ones come up, the tools can. Otherwise they could not be made. If I want to communicate about fish – how beautiful they are or how good to eat – gestures and joint actions would be enough. You might think I could relate about fishing gear in the same way. If I wanted to teach my grandson how to catch fish with a hook, I could take him and let him watch. But without my advising him verbally while we are at it, he might hurt himself at the hook; he might be misguided by the different objects I draw up; no fish might show up that morning, or the wrong kind only. I can teach what I want to teach without words. Sure. I can also catch the fish I want to catch without hooks. A bear does. And he teaches his cubs as well, without talking about it. But I am not a bear.

Verbal language and elaborate tools are (the?) two distinct human characteristics. I would like to speculate that the two evolved together, since one needs one for the other. But it would be impossible to prove or disprove such a thesis. The similarites between these two achievements, however, are striking. Both talking and using tools serve definite purposes. Except for simple cases both tools and sentences can be broken down into basic parts, and reassembled. Some of these basic parts themselves serve as statements or tools, respectively. Like sharp stones or sticks, like exclamations or search calls, they are directly taken from nature. Others, like screws or connectives serve to hold things in place, but are of no value separately. When men became more sophisticated, they developed more complicated artifacts for doing heavy or boring tasks: Machines for grinding or throwing, say, and formalisms for calculating or reasoning. We need formalisms to communicate about machines, in an even stricter sense than we need ordinary language to communicate about tools.

So, although I said that one cannot take back what one said, I take back that language is invented against nature. With tools and words we humans just pushed evolution onto a new level of “formality”. Everywhere in nature forms evolve from processes, and give rise to new processes. So, as we saw earlier, concepts evolve from thoughts, and give rise to new thoughts. The bold “invention” was to take concepts separate, to attach words to them like handles, and then use these handles to combine them into statements.

Statements thus do not represent thoughts. Thoughts stand for experiences that I made or heard of or made up; that is their “meaning”. If I want to talk to you about what happened to me yesterday, I analyze my memories for what concepts they involve and how. Then I combine the corresponding words and tell you: “Yesterday night I saw the wild things do their rumpus.” Depending on the concepts you attach to these words and how you translate their combination back into thoughts, you might be startled or bored or fail to understand.

Thus we return to the writer and her readers with a different picture. The writer cannot let swim her fish over to the readers’ coves. The passages are blocked, or the distance too great. Writer and reader cannot communicate directly and thus symmetrically. The writer has to can her fish and sell them, or send them by mail. For that she needs tools. The readers have to open the cans for which they, too, need tools. Only then can they look at the fish they unpack, find similar ones in their cove, and combine them in a way that seems fit best to the arrangement in the can. Off they swim!

You might ask wryly whether the writer has to cook the fish for canning, and how the readers uncook it. You attest thereby that I have misled you by the ambiguous fish picture. Sentences are composed of words, which stand for concepts. The can does not contain fish – surely thoughts cannot be canned –, but their genetic representations. Communication involves gene manipulation.

Now the picture is complete. I want to communicate about yesterday’s exciting experience. I see the plump figures hop up and down or dangle from trees, I hear them shout their obscene chants, I feel the ground vibrate under their massive feet, I smell the stench from their ugly bodies and taste the fumes from their nostrils, I am afraid of their claws, and laugh madly with fascination. This Maurice Sendak is great I think, and realize that my grandson takes the picture book much more calmly. At age two he is more excited to see Max chase the dog with a fork. With forks and dogs he is familiar; he can easily imagine himself jump at the dog – with a fork, what an idea! The wild things are rather remote to him, not scary, but not so exciting either. So in order to share my experience with you I pick out the aspects described above, find the corresponding words, and start to write:

“Yesterday night I saw the wild things do their rumpus.” What you will make out of this beginning will depend on whether you know the book or ever danced a rumpus, and whether you like children or other wild things. You will make out something.

Actually the same can be said about oral communication. I oversimplified in the first part of this report when I let you send fish from one cove to another. Verbal communication, whether oral or written, involves words, which are handles on concepts, i.e. forms. Compared to thinking verbal communication is formal, manipulative: I hand over some code, you construct some fish. The only difference is: In a conversation I can see your reaction and correct or add to my statements. In writing I cannot, and thus have to anticipate your and indeed all possible reactions, and have to take care of those I care about. Writing is like handling a tool under the table where I can’t see what I do. Writing is like hammering blindfolded.

Thinking is a process, as everything it involves: thoughts, experiences, events. Talking is a process, too, but it involves forms only: sentences, words, concepts. We *form*ulate our thoughts in order to share them. This makes communication so difficult, albeit exciting. The real problems arise when we go one step further and want to convince people of our ideas. Now we want to prove what we say. And to make it fool-proof we might go a final step and *form*alize the matter. Before I can turn to formalization, however, we have to look more closely at how we humans manage with tools and language.

2.3 Does this make sense?

“Yesterday night I saw the wild things do their rumpus.” By now you might know what I mean. If not, look up the great picture book by Maurice Sendak. Got it?

Even if you know what I mean, does it make sense? “Definitely not”, you might say; “not in a paper on evolutionary thinking.” “Not much; I couldn’t quite figure out where you want to get at.” “It made sense enough to make me switch over to read Sendak instead of your report.” “It made a lot of sense to me. It helped me understand that talking and listening involve formulation and deformulation, and thus are quite different from thinking.” How can the same innocent statement make so much sense, or none at all, to different people?

The sentence has a definite meaning. It might not be clear to you if you don’t know wild things, or me. We can argue about it and try to clarify. It is possible that we do not succeed. You might be a serious person and maintain that when I say I saw something I must have seen it, or else be a liar. I would infer that you don’t have children, which might be a misunderstanding on my part. In any case I can get your deviating meaning, and trace it back to a different interpretation of words, to a grammatical construction I did not intend, or to an epistemology I do not adhere to.

We cannot argue about the sense. The four imaginary people quoted above may agree on the meaning of my statement, but for all of them it made sense differently. And I could not go after them for that. Sense is not right or wrong; sense must be there before you can start thinking about right or wrong. Sense must be there before you can start thinking. Sense is basic for anything that goes on in your cove. Also, the question whether something makes sense does not come up in communication only. What you perceive makes sense or not, or not much. Sense is the way how some new fish fit into your cove.

Consider a niche in your cove dreaming away lazily. Suddenly new fish arrive. They might be brought in by some experience, especially by communication; or they might come from another niche, touched off by your own thoughts. Off they swim. But will they? They might be crooked or unhealthy or too weak, and just not get off the ground; they do not make sense for you. Or they might swim off lustily, but get eaten or driven off or lost otherwise, and thus are not accepted in the niche; again they do not make sense. They make sense if they interbreed, changing the niche thereby. Anything new makes sense if it fits into your cove, albeit altering the direction of the development. When it makes no sense you cannot work with it; you can only try to repeat the experience or to look elsewhere in your cove. When it does make sense you can try to figure out the meaning. Meaning is a relation, sense happens. “Sense appears in the form of a surplus of references to further possibilities to experience and to act”, defines Niklas Luhmann in “Soziale Systeme”. Sense shows us where, and where not, to go.

Thoughts have meaning, I said; they mean the real or imaginary experiences from which they resulted. They do not represent the experiences, since they evolve. They evolve through and into concepts though; these concepts are stable, and thus can be named by words. From the words I form a sentence that seems appropriate to the thought; in this way I attach the meaning of the thought to the sentence. Note that thus meaning involves both, a development and a coding; it involves change and choice. Now I make my statement, and expect you to get the meaning. How do you? If there is a word you do not know, you are stuck. If you know all the words and can figure out the grammar, you take the sentence as a mesh of concepts, decode it into thoughts and let them swim. If they make sense they will develop, thus forming a new species or influencing an old one, which you take as the meaning of the sentence. Thus a sentence *has* a meaning to both speaker and listener, but it *makes*, or does not make, *sense* to the listener. Making a statement is like putting up a sign post which everyone can read and quarrel about the meaning. But the post points into a certain direction, depending on where you put it on your property: “North” or “South” or “Southnorth” or “Go back” or “Don’t move!” Meaning is public, sense is private. All I can do is put out more sign posts in response to your questioning or blank look.

I took the distinction between ‘sense’ and ‘meaning’ from the logician Gottlob Frege, although he conceives these concepts quite differently. First he distinguishes between ‘sense’ (*Sinn*) and ‘meaning’ (*Bedeutung*, often more fittingly translated as ‘reference’): In a given situation a sign, for example a word or a sentence, *refers* to an object or an event through the common *sense* it has for all of us. Thus, since we “know” fish (Sinn) we can use the word to refer to (Bedeutung) what we see there in the water, or to fish in general. Then Frege distinguishes both ‘sense’ and ‘reference’ from the ‘associated idea’ which presumably is a mental representation of the thing referred to. I do not separate mind and world, and thus this representation business – signs representing ideas, ideas representing objects – going back and forth between mind and world does not make sense (sic!) to me. I do construe as separate, however, language and thoughts, not so much as external and internal, but as form and process. Thus I will have to come back to the question of how we agree on the use of words. Before I do that I will look at the bodily basis of both, thought and language.

2.4 Image schemata and metaphors

Our basic experiences come directly through our senses: We see, we hear noises, we smell and taste, we touch and are being touched, we go with the rhythm. We carry these impressions in our memory as we do with conceptual thoughts, and we may picture them as evolving nonconceptually, as "primitive" forms of life evolve nongenetically. With lower life forms this is as far as experience goes. In higher life forms – and I do not maintain that I could draw a line here – sense impressions touch off what I have called 'thoughts'. We handle our experience through thinking; we repaint our images, suppress the foul smells, modulate the rhythm. In particular we take the images apart, work with the parts, combine them in fresh ways. I am using 'image' here as a generic term for all kinds of sense impressions, as it is often done. Actually we are most adept in handling visual images, as the word 'handle' suggests. When we move our hands through space, handling objects, taking things apart and putting things together, we control and coordinate these actions mostly through our eyes. It is hard to imagine (!) how the blind do it.

Thus not only are our thoughts touched off by sense impressions; our bodily actions – and in particular our visual perception thereof – determine the ways we handle them. This is the pervasive theme in Mark Johnson's book "The Body in the Mind" as I described it earlier. Through *image schemata* and *metaphors*, like the "container schema" and the "more is up" metaphor, we connect sense experiences and language and transfer the resulting structures to the remotest abstractions. I advise you to read the careful analysis based on the rich material provided in Johnson's and Lakoff's books. I also recommend the classic "Visual Thinking" by Rudolf Arnheim [1969].

I have to fit that now into the fish cove more precisely. A new thought – whether touched off by communication, or other experiences, or directly by thinking – makes sense only if it develops in the niche into which it fell; the developed species then is the meaning of the thought. Developing takes time, and is not predictable for sure. A wild thing swooping down on you might be deadly if you have to ponder on the meaning of 'down' or 'wild'. So "for survival" animals have developed a mechanism that saves them from that time and risk. Through this mechanism, what would take many generations of fish to evolve becomes established in a flash. Fish falling from heaven. The same mechanism works when you hear me say that a wild thing is swooping down on you, although it may take you longer – may even require some questioning – to imagine (!) what this wild thing might look like. I do not like the word 'mechanism' here, since it implies automaticity and infallibility both of which do not occur in nature. Image schemata may fail, or lead us astray. I have no other word though. And in general image schemata transform in a flash – what took us years to learn as children and eons as human kind – sense impressions into vivid thoughts from which we form sentences that we can manage, take apart and recombine, give away and get answers to.

Metaphors work similarly on a different level. If you remark that prices for children books climb up steadily, I understand you at once, although prices – not even for children books

– have no legs and there are no trees around. Through the human ability to think metaphorically – I do not think animals can do this, as they do not normally understand jokes – we translate the expression into a picture of an “ascending” curve, and that again into the sad picture of more money to pay for books and of less money left in my wallet. In termini of fish our metaphorical ability takes the species ‘climbing up’ which would have to die in the money environment for lack of trees and oxygene, and translates it into ‘becoming more’ which needs neither and thus makes only too much sense there.

In our verbal culture metaphors are normally understood as linguistic mechanisms. In fact, we are almost obsessed to attach meaning to anything that makes sense; therefore image schemata seem to create meaning and metaphors seem to transfer meaning. Through the metaphor “Thoughts are fish” I can say about learning what I know about evolution. But actually the metaphor does not just operate on words. Rather what makes sense for fish now makes sense for thoughts; meaning comes later. It is the main thrust of the Johnson-Lakoff theory that image schemata and metaphors are not just linguistic enterprises, but apply to nonverbal and nonconceptual thinking as well, and in this way help build up conceptual thinking. Metaphorical mimicry works on all mental levels.

In this report I am mainly interested in conceptual learning, which involves language. Thus I leave untouched the whole realm of non-verbal representations: images, especially paintings, sculptures, music and dance, but also graphics as a mixed form. In our culture this realm has turned into “art”, strangely separated from all serious communication, rather related to religion than to everyday life. To us, even linguistically, only the whole is holy; what we can take apart and recombine, like tools and sentences, is profane. We forget thereby that all our experience is holistic first and only then translated into language. Here the “terrible predicament of the writer” which I brought into the beginning of this report from Annie Dillard’s “Writing Life” becomes a deeper meaning. The writer sits at her typewriter or computer desperately trying to create a world that she can share with the readers, but we condem her to write “fiction” – dream things, texts that are of no practical use since we cannot take them apart. She should not complain: She can get away as a holy, though mad, person; it is the critic who is in a real mess: He has to take the text apart as if it were a verbal representation of God-knows-what. Only today some scientists begin to realize that art makes sense in a basic way which symbol sequences do not. Or rather: Symbol sequences make sense only through long chains of translations which start from holistic experiences. So in computer science one asks for ways to design computers and their formalisms “as if people mattered”. I will now look at these chains of translations, and return to the problems of formalization later.

2.5 Categorization

I have been mean to call the writer ‘desperate’. Did not I make her look desparate through my theory of communication? Did not I separate her from her readers? Actually all of you who followed me this far ought to be desparate by now, because I tried to make you feel lonely. You think you communicate fine, with your girlfriend, your grandson, your mother; it works also with your neighbor, with the busdriver, with your competitor at work, and even with your outright enemy. Now I tell you that you cannot really. You cannot exchange your thoughts directly. You have to foster them until they breed concepts clear enough for you to grasp with words familiar enough for you to combine into sentences. And your partner has to do the same in reverse: take the sentences apart by finding the intended grammatical structure, guess upon the intended meaning of the outcoming concepts and their relation to each other, translate the sentences into thoughts correspondingly, and have them breed in their cove. That does not only sound complicated. There is so much chance involved, both partners have so much choice, that communication seems outright impossible. Communication is a joint venture. I turned it into an adventure where the partners are barely joined. I turned language into a private business.

Let us look at this "private business" again, that is, at the relation between concepts and thoughts. Don't forget the fish. Concepts are not abstract entities separate from thoughts. Concepts *are* thoughts, in a coded version, but not less alive. Concepts are not bricks which you arrange and rearrange. Concepts are fish in schools, swimming distributed with your thoughts. Words are fish in cans, but if you look at them they carry all the irridescent colors of the concepts they name. Words are concepts made visible.

It is a philosophical misconception handed down from Plato that words, or concepts (often not distinguished), are names for classes, or categories, of objects that share certain properties. Thus a concept catches an array of properties that uniquely identifies the members of the corresponding category. For example, humans are "featherless animals that walk on two legs, but not penguins" or "intelligent animals" or "animals that use elaborate tools and language"; today some would say: "Humans are animals that produce and use external intelligent systems." Many of the problems that we have been grappling with originate from this tradition. For example: Concepts are entities in the mind; as such they are separate from the objects named; the defining objects are themselves concepts, which leads into an infinite regress or into circularity, as the above examples show.

In the early 1970s Eleanor Rosch, with others joining in or following, started a research program on categorization. Through many observations and experiments she showed that our use of concepts in several ways is not consistent with the above "logical interpretation of categories". Here are some salient points: Categories are not formed arbitrarily from given properties, but rather they come up strongly or weakly or not at all, just as the corresponding objects do in nature. For example there is always a "most basic level of categorization" which is used most generally and easily, like 'fish' as opposed to 'catfish' (too special) and 'water animal' (too general). Members of a category are not treated as equivalent, as they should be since they share the same properties; rather there are prototypes (ideal or typical members, like 'trout') as opposed to marginal members (like 'shark') or outright non-members (like 'whale', called 'Walfisch' in German).

There are many more points. You should read papers like "Categorization of Natural Objects" [1981] with Carolyn Mervis, and "Prototype Classification and Logical Classification: The Two Systems" [1983], or the book "Cognition and Categorization" [1978] which she edited with Barbara Lloyd. Some of the results are presented in the books by George Lakoff and Mark Johnson. Our conceptual image of the world is not a uniform system of uniform classes ordered by set inclusion, as the logicians would have it. Rather categorization is structured in many ways; categories are useful tools of many kinds, not just containers.

Categories are fish in schools. They do not come prefabricated elegantly for us to find and use; rather we breed them through our own experience. A concept is more than the class of its members, since it is structured by the way we learned it. It is skewed, since it covers the examples that we started with or that became crucial otherwise and contains other members of lesser importance. We access it not through its description, but by repeating – in a single jump – the way we learned it. Therefore concepts are not abstract, but full of emotions, bodily experience, memories of social events. We cannot tell a lie, or tell what a lie is, without going through the bad and good feelings of lies told and being told. Our concept of a dog depends on whether we have been bitten by, or played with dogs; the dogs of our childhood will always remain paragons of doghood for us.

Did I make things worse? Through the evolutionary model of concept formation I can understand prototypes and the other pecularities of categorization Eleanor Rosch found. But if concepts are bred in my cove, then categorization is really my private business. How can I use words for communication if the underlying concepts are my very own? Language must be universal, otherwise it is of no use. If you say so, you must have forgotten half the picture. Learning is not a lonely activity. Learning is *inter*breeding. We learn through experience, especially through communication. If a child grows up with wolves it becomes a wolf, although a strange one. If a child grew up without bodily experience it would not be able to live. With the help of image schemata and metaphors we carry these basic experiences all the way up to logical reasoning and abstract thinking. Therefore even philosophers can talk to each other (although they never agree). Concepts are not out there in the world, but they are not entities in the mind either. Schools of fish gliding through my cove picture my conceptual system *and* the world how I am familiar with it. I am familiar with anything we share in our family. If you rightly object to mankind being a family turn to a later section where I will talk about how we keep systems small. I have to settle another question first.

2.6 My self and values

I experience my body as demanding and wanting. I experience my feelings as carrying me or as letting me down. I may even experience my thoughts: Normally they flit by unnoticed; but when I search myself for something I want to say, some conclusion I want to draw, some lost memory, then I see them emerge from unlit depths. From thinking about all these experiences I arrive at a concept of ‘my self’. It is a concept like others: distributed over all my thoughts, changing slowly or suddenly, emerging from and necessary for all my thoughts about myself. And yet it is special: I can imagine losing everything, as horrible a thought as that might be; but I cannot imagine losing myself. I conclude that this concept is intrinsic to me. But when I search myself I do not find my self. From the theory presented I know that I cannot: We can handle thoughts, but we can never touch the concepts pure. In principle one can build a computer that has stored its own description. But my concept of my self is not a description, and it is not directly accessible to me, let alone anyone else. Still, not finding my self is an experience so overwhelming that it is a touchstone for Buddhist teaching.

“God is not to be found,” is a running theme in the Old Testament. “God is not to be known,” is the New Testament’s intellectual version. In some form it is an issue in every religion I know. God, or the gods, or the spirits, or nature are the ground for everything in the life of the faithful. To lose the ground would be dreadful; but it is not to be touched. God is ground ungrounded.

Do I mean that you had to believe in God if you wanted to fully accept the correspondence between evolution and thinking, between mind and nature, which I am unfolding here? No cove without its goddess? In his beautiful booklet “The Sand County Almanac” [1970] Aldo Leopold writes about “thinking like a mountain”. During the first half of this century as a professor of biology at Madison, Wisconsin, as an advisor to the government, and as a weekend farmer he developed the basic notions and insights of today’s ecological movement: ‘food chain’ (as a circle), ‘land pyramid’, the concept ‘ecology’ itself. The mountain Escudilla in Arizona was ruled by Old Bigfoot, an enormous grizzly which came out each spring to get a cow and then “summered peaceable on marmots, conies, berries, and roots”. Everyone lived in fear of that awesome animal nevertheless, so it was finally killed by a government trapper. None of the people involved realized that thereby the mountain lost something worth more than a cow a year: “the spire off an edifice a-building since the morning stars sung together.” Without that spire, without the balance between awe and hunger, between eating and being eaten, the edifice would fall apart. I do not preach, neither religion nor ecology. But if you think that a cove has no face, call it identity, and if you behave accordingly, soon the cove will have no face left. If you feel bound to your self without finding it, why not feel awe facing nature’s veiled countenances?

Feelings did not make it into this report so far. Feelings are different from thoughts, less specific, not “about” anything. Like thoughts they may be touched off by experiences, but also they are up earlier, turning mere events into experiences. How we take an encounter or a remark depends on how we feel about it, and in turn may leave us feeling happy or sad. Feelings are the ground that lets us figure out the world. When we get up in the morning, our cove may lie there serenely or brewing a storm, and these moods bring about the fish we will be able to see today. Alternatively we may think that feelings develop nonconceptually as “primitive” animals develop nongenetically. Or that feelings are like the cells which carry the genes.

Feelings are the way how we value experiences. You feel jealous because you value someone, or the relation to someone, or yourself in this relation, too deeply.Values are to feelings as concepts are to thoughts. We experience our feelings as we experience anything else; therefore we think about them, develop concepts for them, communicate about them. But they develop independently. They deposit silt in some corner of our cove and break a piece off that protuding rock over there. This happens slowly, or through the night; we don’t notice. Values are not to be touched. We handle our concepts with the help of words, but words are of no help with or against values. “If you make a value explicit,” Hubert Dreyfus writes in his book “What Computers Can’t Do – The Limits of Artificial Intelligence” [1979], “it turns from a value into a goal. It ceases to be a value.” It loses its value.

“A thing that has no value doesn’t exist,” Robert Pirsig says in his new book “Lila – An Inquiry into Morals” [1991] where he continus his inquiry into values of “Zen and the Art of Motorcycle Maintenance” [1975]. Values are neither objective nor subjective, rather they create perceiving subject and perceived object: without valuing the situation we cannot perceive anything; without valuing the other person we cannot speak. Values bind self and world together.

2.7 Small systems

If we breed our concepts in our own minds, how can we communicate? I left this stumbling block standing squarely at the end of the section on categorization. We learn through joint experience, especially through communication, I maintained; we become familiar with the world in family-like situations, thus our experience is neither sollipsistic nor universal. What are these small family systems?

We are all familiar with small events, and thus can talk about things being small or large with the confidence that we mean roughly the same. In “Gulliver’s Travels” we are reminded that ‘big‘ and ‘little’ are culturally biased. And when you are a tiny person and I am fairly tall, we might have different ideas about smallness, too. But we can talk about them and try to match them.

With ‘system’ it is not as easy. “If you don’t know what it does, call it a process; if you don’t know what it is, call it a system,” as the saying goes. I am a mathematician working in theoretical computer science, and thus am used to think of a system as a set of elements with relations between them. Someone involved with computer design in praxis might visualize a system as consisting of certain units connected by communication channels or cause-and-effect links. Today biologists discern living systems by the way how they relate to other systems and to themselves. A living system is permanently in exchange with its environment; thus it cannot be meaningfully defined as separate from it (as a relational structure, for example). If you cut an animal off from its environment, it dies. In the same way you cannot take away a part or a member of a living system without changing it. If you cut out an animal’s heart, both the animal and the heart die. Today one transplants organs of animals as if they were physical systems; but nobody knows how badly they are changed thereby. Or take my family: There is my wife and our four boys, not to mention our grandson and his mother; and, of course, Bobby the dog, I am sorry. Still this is a rather meager description, I have to tell you more about them. Most of that, however, would relate to the family situation; so this is a circle with no beginning and no end. Living systems are self-referential. Anyway they consist of processes, Niklas Luhmann adds as a sociologist; they are not static, but unruly (*unruhig*); to see a social system as people communicating instead of as communications, is just a matter of convenience. I stated earlier that I would not go quite this far; but surely the mathematical definition does not work for me anymore.

If ‘system’ is so controversial, how shall we agree on ‘small system’? There is no mathematical definition, and there never will, as I see it; we can measure size, but ‘small’ and ‘big’ are relative. Systems theorists do not dwell on the issue either, likely for the same reason. There is an old paper on “The characteristics of large systems” [1979] by the computer scientists L. A. Belady and M. M. Lehmann. They call a system ‘large’ if it cannot be designed by a single person, and collect pecularities of such systems. In contrast to this situation I maintain that the notion of small systems is universal in the following sense: If we want to communicate, we have to keep the system small. If we let the system get out of hand in any respect, we turn mute and deaf as if from too much noise or too strong a silence. There is no physical law involved, and insofar the effect is dependent on people and situation and culture; still the phenomenon itself is universal.

We all know what happens when a system grows in size. As example take a teaching situation. First we have to increase the *means* and make the *rules* stricter: We need a larger room or even a lecture hall, a blackbord, maybe a microphon; we have to be stricter about time, we have to split into groups and have to set up criteria for grades. Second the way we think and talk changes: We have to be more careful about the *words* we use, we have to explain our ideas in more detail, we have to straighten out our *concepts*. Further our *values* become affected: As teachers we cannot care about the individual students anymore; and the students will care less, or rave, about the teachers, since they do not get to know them well enough. And finally our *will* (intention) becomes more rigid, we might be overdetermined to succeed, or couldn't care less.

A big system is thus excessive in some respect. It becomes more important than its participants, puts itself in between them, and thus hampers their communication. A too small system may hinder our work as well by being defective, and in this way enlarge the distances between the participants.

Exactly the same changes, however, may occur in a system of fixed size, with a small number of members. As example this time take a small research group, consisting of a few scientists of different status, a secretary, and a programmer, assisted by computers and other machinery. The system is fixed in size, neither too big nor too small. Nevertheless it can be excessive or defective in other respects, and thus fail to be "small", as follows: The *means* can be poor or overwhelming, as in a broken typewriter, too much money, a universal theory, no room. The *rules* can be rigid or uncertain: All work according to schedule X17; everybody may change the editor, or go on vacation, or drop out of the project, any time. The *language* and the *knowledge* of the participants can be fixed or shaky: The programmer stammers at the keyboard, the theory is overly formal, the concepts are schematic or weak. How do the participants *value* the situation? They can be indifferent, or overrate their work or their co-workers by being contemptuous or submissive. Finally the *will* is most important: A participant – chief or underdog – can be overdetermined to do a good job, or feeble-minded.

Under such extreme conditions the communication in a system becomes increasingly difficult; but also conversely, when the communication is endangered we react by tending toward such extreme conditions. Therefore I call a system *small* if it is neither over- nor undersized, that is, not stuck to either extreme, in any of the six dimensions, which I call *bearings*. To keep the system small, the participants have to use simple means and loose rules, they have to converse intimately and think flexibly, they have to care for each other and for the work, and they have to do all this freely. And I maintain that we communicate freely only in small systems.

Let me add two observations: (1) The bearings are not independent: A system that became stuck in any of them is likely to become extreme also in the others. Therefore the word 'dimension' is bad. (2) I listed the extremes in pairs, but in each case there might be more than two. And surely ‘small’ does not mean to keep the golden mean, but to alternate freely between the extremes.

So far this is phenomenology. I have used this definition of ‘small systems’ for ten years now in many situations, and found the thesis concerning communication to work everywhere. You should try yourself. I learned a lot from books, like “Walden” by Henry David Thoreau [1962], “A Sand County Almanac” by Aldo Leopold [1970], “Pilgrim at Tinker Creek” by Annie Dillard [1974], on ecology; “Small is Beautiful” by E. F. Schumacher [1974], on “economics as if people mattered” (subtitle); “The Unsettling of America” by Wendell Berry [1978] on “culture and agriculture”; “Zen and the Art of Motorcycle Maintenance” by Robert Pirsig [1975] and “The Concept of Mind” by Gilbert Ryle [1949], on philosophy; “Soziale Systeme” by Niklas Luhmann [1984], on sociology; books on group dynamics in education and psychology; “The Tree of Knowledge” by Humberto Maturana and Francisco Varela [1987], and “Steps to an Ecology of Mind” [1972] and “Mind and Nature” [1979] by Gregory Bateson, on evolution and much else. You will find more in the extended annotated bibliography of the forthcoming book “Formale Methoden und Kleine Systeme” [1992] which contains (in German) some of my papers on the theme.

But again, how does the theory fit into the fish cove? How can it help to solve the problem of communication between evolving minds? That our mind needs support to evolve is obvious; permanent defects in any respect hinder evolution. That the same is true for permanent excess is against common belief; but it is as obvious for an evolving mind. Too much of anything weighs down the interchange, our minds become separate. Don’t we feel lonely in large systems? We bring in more support to keep the communication going, and just thereby make it break down. Our life makes no sense except in small systems. Thus in the cove of our mind small systems come in, and pay off, as healthy niches. Such a niche is open for communication and thus for change, but it resists infestation.

So this is my simple solution to the “problem of communication”: The problem does not exist, except life itself be a problem. Whatever happens to us happens in a social environment. Even the saint on a pillar has God as partner, or he hopes to be God’s partner; and if he is a saint indeed, he will not exclude those who bring him food and see him sit there. (Did I say “he”? Yes. If there are typically male ideas, ‘sitting on a pole to please God’ must be one.) And we exist in a social system only insofar as we keep it small. Otherwise it does not make sense.

There are people in Artificial Intelligence who liken humans to computers. Others, like Hubert Dreyfus, rightly argue that there is so much “what computers can’t do” [1979] but humans can. But there is enough as well what humans can’t do but computers can. Most basic seems to me: Humans cannot behave deterministically. Computers are, like all machines, deterministic; so are the man-made “neural networks”. They run through physical states in a prescribed way; thus when the same or another machine is started in the same state it will always do the same. (Computers or networks with random sources are no counterexample. They are good for probabilistic results, but worthless as individuals. The statistical behavior of humans en masse, like that of computers, can be modelled mathematically; but that is not the issue here.) Now you try to follow a set of rules precisely. Even if you succeed, you will not be able to suppress thinking alongside: How silly or smart the rules are, or you for that matter, to follow them, and what there might be for dinner tonight, maybe you should not drink as much wine as yesterday, if only... When you realize terrified that you are off the track, you may have lost track completely, and have to start all over. No task is so stupifying as to try to understand an algorithm handed in by a student, through simulating it. Nothing is more degrading than to be forced to follow rules without choice. It is considered inhumane, because it makes no sense.

Human choice runs on many legs. I call them bearings, since together they bear sense. The objectivists ground their sense of life in the material world; the subjectivists, in their minds; the faithful, in their values. Sense, however, does not rest in any of these; it resides in their free interplay. Already the higher animals do not behave deterministically; they think, and thus act, freely; we say that they are bound to instinct, because they seem so single-minded. We humans went further, “inventing” tools, language, and values. We would be overburdened by so much possibilities, so we “invented” sense alongwith to keep the choices down. Sense does not just consist in the possible ways to go on, as Luhmann would have it. Their number has to be small to make sense to us.

3.0 Keeping formal systems small

A thick spawning of fish, a bedful of fish, is too much, horror; but I walk out of my way in hopes of glimpsing three bluegills bewitched in a pool's depth or rising to floating petals or bubbles.
Annie Dillard "Pilgrim at Tinker Creek"

3.1 Formalization

You are a student in a logic course. Mathematical logic, not that mushy philosophical stuff. The teacher talks about 'logical consequence'. The statement A "follows logically" from a set X of "axioms", she says, if A is true whenever all statements in X are true. She gives an example: "It rains" follows logically from "It rains" and "It pours" because it certainly rains if it rains and pours. You grant her that and feel sad, while the sun shines brightly outside. You tell the teacher that her explanations do not seem to help you with your homework; you are asked to prove that commutativity of addition follows logically from the Peano axioms. Your teacher had just before convinced you that the Peano axioms – a couple of elementary facts about computing with natural numbers – are true; that addition is commutative – that is, 2 + 7 = 7 + 2, and so for all pairs of numbers – you learned in grade school, although not by logic but through rote learning. So what is there to prove?

From her terrified look you realize too late your blunder of speaking up. This all is a consequence of your not being attentative enough, she says sternly, and goes over the definition again. You don't listen, because you were struck down early on by her using the word 'consequence'. Does your stupidity follow logically from your inattentiveness, you wonder; and if so, why can she just say it without proving anything? There is one consequence you are sure about: If you fail this course, you will flunk the term. There is nothing to reason about that, which does not make you feel better.

Later you talk it over with a friend who has successfully studied logic. There are many types of consequence, she explains; your teacher probably wanted to say that your inattentiveness causes you not to understand the definition. You can use logical consequence only if everything is formalized, that is, if you disregard the meaning of the words and just look at the form of the sentences. Your teacher should have used "It debbles" and "It pabbles" instead of "It rains" and "It pours"; what she wanted to say is that whenever two statements are true together each of them is true separately. "But I know what the Peano axioms mean," you insist; "and I know what the natural numbers are: 0,1,2, and so on forever. How can I disregard that meaning?" "The logicians hoped to describe the natural numbers by axioms," your friend replies. "That is, any structure satisfying the axioms should, in some sense, look like the natural numbers." "And I know your teacher," she continues. "She is careless, normally she forgets an axiom, or gets it wrong. Let's try to construct a weird structure she has not thought about that satisfies her axioms, but violates commutativity." This sounds weird, but exciting; and sure enough after many tries the two of you come up with a monster structure that besides 0,1,2, and so on, contains four numbers which you call hop, pop, plop, and stop and where hop + pop = stop, but pop + hop = plop.You shiver. "Of course," your friend cries. "I should have known. She forgot induction. Let's plop that in." You do, and try, and the monsters are gone. No matter how many hops you pop in, they do not stop addition to commute. This gets you on the right track to the proof: You take two arbitrary things x and y – you call them “pebbles” to make sure that they are neither natural nor numbers – and dabble with them using nothing but the axioms, until you have proved that $x + y = y + x$. Late at night you have shown that in any structure of pebbles satisfying the axioms addition is commutative. You shake. The wings of formality have brushed you.

Here I leave you alone with your logic friend. (If no wings brushed you while reading, just read on. I did not put in this example to teach you formalization, but to give you the general flavor. Even if you have never been exposed to abstract mathematics, or else bruised too badly, you might still learn from the following.)

What now precisely does formalization mean? In one of the early sections I introduced the Bateson ladder between process and form. Formalization means an extremely long ladder, steep as hell, ascending directly into the heaven of formal concepts. But a ladder it is. The logicians may hammer into it as many nails as they want, you have to climb it by going through process after process of experience to get at the formal concepts. Let a concept be defined as formally as will, you have to learn it through working with it. And when you work you are always with fingers and nose into reality. Formal concepts are pure, that is, given by a few, strong characteristics; but concepts they are. What the two logic friends did not know: Formal concepts always rest on informal ones. You can define ‘structure’ and ‘formula’ and ‘logical consequence’ formally. But the words you use thereby are informal. Formality grounds in informality, and this ground cannot be chosen at will. Alfred Tarski proved that ‘truth’ cannot be formalized. Kurt Gödel proved that the natural numbers cannot be formalized. These concepts are the body and backbone of logical formalisms. The meaning of logic rests on them and on everyday language in the same way as the meaning of everyday langugage rests on bodily experience.

Following the Italian humanist Vico, the philosopher Ernesto Grassi distinguishes between rational and rhetorical language, for example in his book “Rhetoric as philosophy” [1980]. In no argumentation we proceed wholly rationally; rather we use all our human faculties to lay open, or hide, our assumptions, for example. In my paper “Prototyping is Theory Building” [1989] I extend his observations to science. Even in mathematics rationality is upholstered by rhetorics. Not only that we have to make the axioms plausible – we cannot prove them lest we run into an infinite regress or a circle –; the proof steps themselves are argumentative, not logical. We cannot wrestle down our partners by rational arguments, we have to convince them. ‘Truth’ has the same Indo-European root as ‘trust’, not ‘thrust’.

Why then are arguments so forceful? ‘Argument is war’ is the first metaphor George Lakoff and Mark Johnson introduce in their “Metaphors We Live By”. And they are right: That we talk about argumentation in war terms reflects only that we feel and behave like warriors when we attack our opponents with cunning strategies to throw over their mental strongholds. In the god of reason we trust, and the battle is ours!

Logical arguments are carried through by basic bodily experiences, Mark Johnson argues in “The Body in the Mind”. Statemements are associated with containers: they are true in some situations, and false in others. For any statement and with any situation we are either in that truth realm or out of it. Thus, for any statement A, either A or not-A is true, which "law of the excluded middle" is most basic for classical logic. Or to come back to the teacher's example in the beginning of this section, if we are in two truth containers at once, we are surely in both of them: "It dabbles" follows logically from "It dabbles" and "It pebbles". Nobody can resist that argument. The laws of classical logic can be spelled out as laws of set operations, thus of experiences with containers. But logic need not be so irresistable. In the logical school of Intuitionism statements are not associated with truth containers, but with provability; and if I cannot prove A I need not be able to prove not-A, it might be that both are not provable for me. Therefore the Intuitionists reject the law of the excluded middle.

What does the fish picture tell us about formal arguments? In part 2 of this report I pictured Mark Johnson's image schemata as mechanisms of inheritance of very strong, and thus universal, characteristics. If I climb up a tree, the experience of 'up' produces strong up-fish in a perfect environment so that they multiply and dominate the niche at once. And if I then become careless and fall down, the then-fish and down-fish are sure to follow. Logicians rely on fish that carry such strong characteristics as purely as possible; they concentrate on those and promote them through artificial breeding. Logic is but a fish breeding factory!

Thus I hope I have finally explained your woes with logical consequence and Peano axioms in the beginning of this section. Note that by 'explain' I mean that I unfolded a colorful and distinct picture which thus laid open shows you the situation in plain light; just forget the aggressive connotation 'to explain' has had to you. You might know or can easely imagine how difficult – risky and costly – it is to set up a factory. Once it runs and you have acquired customers, machines and hired labor work for you, and you sit in the sun and eat cake. "Mathematics is so easy, only to get the business started is hard," a good mathematician reportedly once said.

Of course there are risks and hard work all the way down, not only problems with the beginning. Every manager will but laugh at the idea that she sits in the sun and eats cake. Also with the best effort you may loose contact with the world, and what good is a factory without customers? Your fish might become infertile from too much inbreeding, and your production dies down. A disease might jump into your too well protected colony and kill all the fish. The breeding might get out of control, and suddenly you have fish all over, or fish nobody likes. Or you start to hate your fish or the business. Then there is cheating, as always in business. Peddlers sell you stock that is unhealthy or poisonous to your fish. Merchants come by with a glass tank on wheels, perfectly illuminated in intriguing colors exhibiting the most beautifully dancing schools of fish, until you find out painfully that it is all plastics and mechanics and electronics.

But life fish they are, your formal fish. Or rather, life fish they better be. Dead fish do not evolve; so from dead fish you do not learn. The alternative is not "Fish in schools or fish in cans". Canned fish could not be raised back to life. Rather your choice seems to be between natural and artificial breeding. But again, neither extreme would do. The priests of nature will come at night and shit into your breeding basins, cursing your sinful business. The priests of artificial intelligence will come at daylight and tell you that three years from now coves will be replaced by concrete basins, and how the world will ever be so happy and square. Both kind of priest will try to use force, of words or swords, of arms or of twisting arms.

In part 2 of this report I showed you how to keep your systems small by balancing gracefully between terms that are to heavy or too poor to live under. Today you cannot raise your children running naked in the backyard until they are too old to go to school. But to implant them into a computer would not do either. As a mathematics teacher you should not stretch your students onto the bed of your most powerful formalism, because you would harm them, and at best make them hate mathematics. But if you tell them that doing mathematics will turn them into robots, they will laugh at you, since they know that you get paid for your teaching.

You might feel excused because you are deep into research, and see teaching as a duty or as a way to get students. Let others devote their energy to education; you are not interested in didactics. But how can you? Have you not to explain your findings to your colleagues? Are they not harder to convince, since they are burried in their own special fields? In doing formal work you have the same problems of getting started and falling into extremes as in teaching it. To deal with them you need not construe the papers you write as either weapons or advertisements; why not as presents or as invitations to dance? You can do and teach formalization the small way. Only then it will bear fruit.

3.2 Do artifacts and formalisms evolve?

Formalisms are to machines as concepts are to tools. In part 2 of this report I wrote about the striking similarities between the use of tools and of concepts, and speculated that humans must have “invented” conceptual thinking and using tools in parallel. Similarly machines an formalisms invite and presuppose each other.

We use formalisms to communicate about automated actions as they are exhibited by machines. The wheel of a steam engine is hinged upon an axis and will turn when pushed in the appropriate direction. There are mathematical formulas that relate diameter and circumference of the wheel; thus we can compute the speed of the engine when we know how often the wheel turns per second. With the help of other formulas we can calculate the pressure of steam needed to turn the wheel with a certain speed, and so on. Thus for the engineer mathematical formulas constitute a complete description of the steam engine. The description is universally valid. The speed depends on the number of turns, and the number of turns depends on the pressure of the steam, today as it did yesterday and will do tomorrow. Although the speed varies with time, the formulas do not. Neither change the involved concepts. A wheel is a wheel is a wheel unless it is worn out and breaks. But even then the concept does not break down. Every living being is “born” at some time, it “grows” and “decays” until it finally “dies”. I use these verbs in a wide sense here; in any case they are constituent to the concept ‘living being’. Although an engineer knows that every wheel will finally break, ‘breakable’ is not constituent to the concept ‘wheel’.

For some mysterious reason one therefore believes that mathematical concepts like ‘diameter’ and ‘circumference’, physical concepts like ‘speed’ and ‘force’, and even engineering concepts like ‘wheel’ are constant. It thus seems that scientific concepts are eternal. But if they were, how were we to use them? Concepts are but the genes in the evolution of our thoughts, was my thesis in the first part of this report. Therefore concepts change slowly when compared to our passing thoughts; but concepts change fast in our own development when compared to cultural evolution. And change they must, as I explained in the last section. Change they will, was my proposal, as long as we keep our systems small.

Now we are in for a problem. Concepts change like the world we describe through them: by evolution. This is what the fish picture shows us. But artifacts – man-made objects – do not change; so how can the corresponding concepts? Artifacts do not develop. They seem to move like living beings, on wheels instead of heels; but they neither grow nor bear children. If we want them to change, we have to change them ourselves. This is of some advantage: As long as they work we can use them for a designed purpose. A car may guzzle gas, but it will not develop drinking problems nor turn into a workaholic. It will not grow a fifth wheel either. Artifacts are reliable. The disadvantages are not as obvious. As artifacts become more involved – from simple tools to machines to complex systems – we use them for ever more involved tasks. With a hammer you can mend a fence or break a window or work at a sculpture. At first you might be bad at either task, but you can always learn and become better and have more fun. As a worker in a car factory you are in a different situation. As long as you are not familiar with the huge machines, they will induce fear, since there is so much you can do wrong. And if you have become familiar with them, your work will become boring, because there is not much left for you to really work on. Completely mechanized work finally will turn meaningless.

Formalisms are mental artifacts, machines for thinking, and thus behave like artifacts: not at all. They do not develop. Even if they, as computer programs, move like thoughts, they neither grow nor bear children. If we want them to change, we have to change them ourselves. And with machines, they share their advantages and disadvantages. Since they do not squirm in our minds as natural thoughts do, we can use them in a machine-like fashion to transmit messages quite precisely. Formalisms are reliable. ‘Logical consequence’ is the same today as defined by Tarski in the 1930s. And the Peano axioms for the natural numbers will not suddenly start to grind an axe of their own and chop off the number 13, say. If you are familiar with a formalism you can use it for designing machines, which would not be possible without; you can save a lot of thinking and bring forth new ideas. Modern science and thus technology could not do without formalism. But there are the same disadvantages as well: disintegration, fear, monotony, action without meaning. Mathematics is a beautiful tool, as most mathematicians say, and it is the breeding ground for formalisms. Still most of us are, secretely or overtly, afraid of mathematics.

Breeding ground? I have jumped out of the fish picture. That’s why I cannot deal with formalisms properly. Let us go back in. Formal concepts are uniform, they all look alike, like fish in cans. In “Prototype Classification and logical classification: The Two Systems” Eleanor Rosh calls this “the logical interpretation of categories”. But still they are life fish. Otherwise they could not swim, not produce new thoughts. With dead fish in our cove our mind would start to stink. No, formal concepts are but bred artificially, formalisms are fish breeding factories.

By calling formalisms machines, I identified concepts and corresponding objects, or at least made them behave alike. This way I made you step into the realists' trap, who let concepts mirror objects, or into the idealists' trap, who let objects exist only in the mind. But formalisms are not mental machines, no more than religion is a mental heaven. Formal concepts are the residua that we build up in our mind when we think about machines. And thinking is always a life process, however reglemented.

Formal concepts are bred artificially, or even produced through cloning. Formal thoughts are pure, and thus poor, conceptually, as cloned fish are genetically. They thus develop slowly in general, and then in wild jumps as if stricken by disease. When the logicians found out that axioms for natural or real numbers do not prevent "monsters", "nonstandard" numbers, to show up – remember plop and stop who hop on pop? – New mathematical fields arose, called "nonstandard arithmetic" and "nonstandard analysis". These fields actually rose from the choppy sea of mathematics like natural beasts and still are considered monsters by most real mathematicians. On the other hand nobody really believes that the Peano axioms could be contradictory, and thus no good to describe anything, not even the number 13. But this belief cannot be proved, as the logician Kurt Gödel proved.

I borrowed the term 'monster' from "Proofs and refutations" by the logician Imre Lakatos [1976]. The book is written as a dialogue; a group of students with the help of their teacher tries to prove the Euler formula for polyhedra. You don't know what a polyhedron is? Well, the class started out with the idea of three-dimensional objects with plain faces and straight edges, like dice and bricks and pyramids. If for such an object you count the faces and the vertices, add them up and deduct 2, you get the number of edges; this is the formula the mathematician Euler proved more than 200 years ago: $f + v - 2 = e$. Try for yourself. When you verified the formula on enough examples, look for a proof. This is what the class did. But when they were done with the proof, one of them came up with a monster: a cube with a square hole cut through it. For such a square doughnut the formula is false. So they excluded polyhedra with holes. But now another monster turned up: a brick with a cube put onto one of its sides. Here the formula works, but their proof broke down. So they reworked the proof. And so on through 200 pages. Alternatingly they elaborate their definition and fix their proof, but never get done. The precise concept of polyhedron eludes them. But they learn a lot of mathematics that way. Actually they cover 200 years of mathematics: What Lakatos presents as a fictional dialog, is exactly what happened to Euler's formula in mathematical history. So the reader learns not only mathematics, but about mathematics as well.

What do we learn from Lacatos' story? Mathematicians do not bring up definitions and theorems and proofs as fishermen haul up pikes. Pikes are rare; normally one finds smelts and seaweed, and turns them into a pike through a little story-telling. Lakatos ends his book with an algebraic concept of polyhedron that is so abstract that it would remind nobody of dice and bricks and pyramids – not a good ending, and I doubt that Lakatos regards it as satifactory. But polyhedra and numbers are not out there in the raw, waiting to be turned into concepts. Rather mathematicians have strong intuitions about their objects and strong addictions to their formalisms. To try to render these intuitions into formal concepts requires a lot of careful breeding to strengthen the wanted characteristics and to eliminate others. The results may look artificial, but they are alife. Like all writers mathematicians do not capture the world as given nor do they create it freely. Numbers and polyhedra and algorithms are to be shaped and reshaped like all tools in order to be useful.

Actually the same is true for machines or any artifacts. A steamboat does not change by itself, it runs unaltered unless someone alters it. But the next model might be a little bit different, depending on our experiences and the engineers' ingenuity and willingness for change. Thus "the steamboat" evolves through history like "the pike" and "the smelt". No steamboat is built without blueprint, no changes will be made that have not been thought out before. Thus I can say about artifacts what I have said about thoughts so far: Artifacts evolve conceptually as fish evolve genetically. Thus the evolution of man-made objects takes place in the mind. When you look at a steamboat it seems unmoved; but when you talk to the engineers, it starts moving like so many fish. Artificial fish, steamfish.

A disturbing difference remains. Both fish and steamboat exist in two worlds, in mind and in nature. Fish evolve in both worlds, genetically in nature and conceptually in the mind. Nature comes first, however, and mind better follows. When my ideas about fish diverge from the real fish, I will talk nonsense; if I insist, they will carry me into the madhouse. But for steamboats there is no such natural line. Steam fish come from the breeding factory, and may be as whimsical as my mind will allow. If my steamboat won't swim and I insist to call it a boat, they might carry me into the madhouse, too. But that is an extreme case. Normally almost everything goes, and goes by unchecked. The aforementioned problems with artifacts and formalisms seem to point to a weakness in the human development. Humans see too many possibilities, and choose among them, and fail to realize that their choice makes no sense. How can we keep our systems small, to live meaningful in an increasingly artificial environment?

3.3 Designing large systems through prototyping

You want to design a system: a computer assisted work environment, a lecture or a book, an office, a steamboat. The system involves people, and is too large to be designed in one swoop. So you choose an aspect, or a submodel, or a level of the system-to-be, and start working on that. The part must be functionable, and must make sense in itself.

You create a first version, a prototype, of that part. 'protos' means 'first' in Greek, and then also 'best'. So you do the prototype as good and as fast as you can or want. Then you test it, and discuss the result with the people involved: those who will use it later, your coworkers, those who ordered the system, and perhaps colleagues or friends. On the basis of the discussion you change the prototype, and start again. You run through this four-stage cycle of producing, testing, dicussing, and changing, until you are satisfied or run out of time or money. You do it with another part and a third, until you are finished. This is prototyping.

If the system is small, you may work on all of it at once. In any case, the part you work on must be made to function (otherwise it cannot be tested), and it must make sense (otherwise it cannot be discussed). The testing is important lest you build something in midair. The discussing is important, since it brings in fresh ideas, new perspectives, and critical evaluation. Without either you could not change the prototype; you would not get anywhere.

A system resulting from prototyping cannot fully be described. Before you are done, and especially when you start, you do not quite know where you will end. While you are at work the system changes. And when you are done, so many people have put their ideas and experience into the project that it is impossible to collect and formulate all of it. (For this reason documentation is so hard.) A prototyped system is self-referential, and thus represents more than any description can show: The system gets its meaning from the way the people involved perceive its working; and the people involved perceive the system through their working in it.

Prototyping is known in engineering, although rarely done exactly as described above. A complex system cannot be created in a single swoop by a single person. Through prototyping one tries to get different people involved, let them experiment with the system under construction, and in this way build their experience into the system. Engineers seem to be less interested in the process than in the result, though. Series production is done after the finished prototype; so this prototype ought to be best, not just first. If one builds a wire model of a bridge to see how it would look like, or a wooden model of an airplane to test it in the wind canal, certain demands of prototyping are satisfied. The future users, however, are rarely involved; if legally required or highly desirable for other reasons they might be confronted with a look-at-model. Serious testing of workable aspects by outsiders is not done; presumably the very idea would give a grownup engineer the creeps.

Also in the world of writing by the word ‘prototype’ one means an outstanding example that will influence the genre over a long period. In that sense the poems by Rimbaud have been prototypes for many generations of poets protesting against encrusted traditions; “Finnigans Wake” is the prototype of a poetic story where the way how it is told is more important than what the story is about; and “The Tin Drum” might be called the prototype novel of the new postwar poetic realism. But presumably such prototypes are not achieved through prototyping. Poets work in solitude, and the future readers are the least they would want to take part in their writing.

Prototyping as an activity has become an important issue in computer science. Computer assisted systems have in common with other engineering products the advantages and disadvantages described above: reliability, costliness, and inhumaneness. There is one strong difference: Other engineering products are expected to be, and normally are, fault-tolerant, that is, they work safely within certain limits, even if they are not fault-free. Computer systems, however, may produce considerable havoc or break down completely upon a single program or machine error. And no computer system, especially no program, is error-free. Computer scientists therefore lament about the “software crisis” nearly as long as they produce software (huge pieces of computer programs as opposed to the “hardware”, that is, the machine the software is run on); actually the field “software engineering” came into existence as a response to that problem. Many reasons are discussed for the crisis: the complexity of software; its “invisibility”, software actually being a mental product; bad education; the missing engineering tradition. Whatever other reasons one might come up with, to me prototyping as described above seems to be the most promising answer to the problem, and to the problem of system design in general. Through prototyping we take into account that engineering systems are designed and built and used and discarded by people. (More on this theme you may find in the volumes “Approaches to Prototyping” edited by Reinhard Budde et al. [1984] and “Software Development and Reality Construction” edited by Christiane Floyd et al. [1992], and in my paper “Prototyping is Theory Building” [1989].)

Recall the fish breeding factory. Software systems, like any engineering products, are artificially bred, they rest on formal concepts, and evolve only in our mind. In this sense they are invisible: The machine you can touch and the program you can read are both dead – canned fish. They are alive only as far as we think about them, and thus keep evolution going. Thinking comes about through communication and experience; this is what we foster through prototyping: Actively in the construction phase and passively in the testing phase we work with the model, thus as designers and users accumulating bodily experience (if only through sight!) which serves as a basis for further mental development. In the discussion phase we share these experiences and try to build them into a coherent picture after which we alter the plan in the changing phase. First of all in this way the viewpoints and abilities of many different people are involved; the system is developed on a broad scale, thus diminishing the danger of “genetic pureness” which amounts to conceptual poorness. Second, and as important, if prototyping is done right, the whole range of human capacities comes into play, as everyone involved may contribute all of her or his practical, theoretical, and emotional strengths and weaknesses. Praxis, theory, and imagination are the three poles around which I grouped the bearings crucial for small systems. Prototyping can be employed as just another technique to make system design less error-prone and more efficient. Done in the right spirit it can help to keep the systems small. It is the activity that counts rather than the result if we want systems to evolve.

In their book “Understanding Computers and Cognition – A New Foundation for Design” [1986] Terry Winograd and Fernando Flores describe design as the interplay between understanding and producing, or interpreting and constructing; the appropriate German word for ‘to design’ is ‘gestalten’, now also used in English. In contributions to the volume “Sichtweisen der Informatik” which we are editing together with others (Wolfgang Coy et al. [1992]) Arno Rolf and I characterize different fields of science and humanities through this pair; already Herbert Simon in his “ The Sciences of the Artificial” [1969] has a similar distinction. Engineers aim at constructions; in the humanities and the natural sciences people work by interpretation; only the architects are explicitely up for design, although people in the social and medical sciences, in law and theology are doing design, too, albeit normally without noticing. Computer science might take a turn to the better if people there took design work as their task. Actually everyone should. Interpreting and constructing build a complementary pair in the sense of dialectics: As extremes they exclude each other. We find the thinkers and the doers everywhere, not only in the sciences; practioneers and theoreticians abound and cannot talk to each other. But then we cannot do anything we do not understand; and the best way to understand something is to work with it. Thus understanding and producing demand and carry each other, they form an exciting unity in design. And this precarious unity is kept from exploding or drying up by communication.

A steamboat, I said, is a man-made object which evolves only in our mind. If I produce one after the other without thinking, my work changes from engineering into mass production, I have stopped designing. If my steamboats explode in midstream or dry up on the banks through steering failure, nobody will want them because they are so poorly designed. The pathes of evolution for a steamboat are as narrow as the water-ways of the Mississippi have been. Cutting straight channels, for example through computer design, will only lead to erosion and thus to the loss of land and more mishaps. Rather I have to stimulate the exchange between experience and new ideas, I have to run the steamboat in many shallow waters and in many deep minds to keep going as a designer. Prototyping is one way to do that.

In designing I have to weigh the wishes and needs, the abilities and means, of all people involved, not just of myself. Designing means to make things the small way, that is, the human way. It might be no accident that the German noun ‘Gestalt’ has no counterpart in English. The unity of a small system, which we call its “gestalt”, cannot be caught. The gestalt is never done. If we think of it as a finished product, it becomes big. To work process-oriented instead of product-oriented is a way to keep systems small.

3.4 Teaching and learning formal matters

Each summer I have to teach a course on “Logic for computer scientists” with about 300 students. This course is my testing and experimenting ground for small systems. An ant-hill – a favorite example of people who want to challenge the small systems idea – will never be a small system unless we would get involved with the ants in a human way; but a hord of juniors who are out for a good grade is a much tougher case.

Of course I could not do it alone. There are two teaching assistants and a couple of graduate students to help me. Traditionally the course was split into a lecture and a tutorial, each a two-hour session per week. In the lecture I would go over the material, in the tutorials we would work with 20 - 25 students to deepen the understanding. Each week the students would have to turn in written exercises where they had to do proofs or examples, which we would grade. The final grade was computed from the homework and oral performance. We used lecture notes in which I motivated the material through problems from logic puzzles or Artificial Intelligence or logic programming or history.

Then we started to implement small systems with the help of prototyping. We cut down on teaching. With an audience of more than 50 the teacher cannot but hand out knowledge, and the students cannot but store it. But neither learning nor teaching works that way. Remember that teaching and learning happen in a symmetrically balanced way, or not at all? In a large lecture the students rarely listen, if they come at all. So I teach less frequently, on general themes like “syntax and semantics” or history or “formalization”. I have not taught on fish yet, but I might this summer. In a textbook I wrote for the course, “Formalisieren und Beweisen – Logik für Informatiker” [1990], I wove these themes into the logic material.

In exchange for the missing lectures each tutorial meets a second time every week in the "logic center". Ideally this would be a fixed room where there is always a tutor present, and students can come and go and work. We have to use ordinary seminary rooms instead where students meet their tutor on an individual basis to report on their "project exercises". These are larger problems, four per term, by which we replaced the weekly bits-and-pieces-exercises. There the students have to, for example, alter a complicated completeness proof to a novel situation, or axiomatize a "robot world", or find "nonstandard models" (see above). Formally this is the sole requirement for a grade. Informally they work in groups of two to four, by prototyping: Each week they show in written form, and explain to their tutor what they have done so far; they get advice, or are consoled; and get back to work on it. The time the tutors spend in the center is made up by the time they save in grading. (Each of us teaches one or two tutorials, so we are all tutors.)

We have done this several times now, also with other courses, and each time it turns out differently. Nearly everything we try works great the first time; thereafter it depends. It does not work if a tutor does not like it. It does not work when the students do not care. My collegues are suspicious because I do not seem to really teach; also in this system the students either get a good grade or drop the course. You cannot weekly face your tutor revealing in person that you have been lazy. (Turning in sloppy homework is much easier.) Under the grip of a collegue who tried the system in his courses, it turned into a seamless student-supervision technique. Small systems cannot be constructed on the spreadsheet. Either the people involved create them; then teaching and learning is great fun. Or they don't; then it isn't.

In the end what we know about a subject amounts to how we can handle the concepts involved. We do not get them handed over; rather we breed them ourselves, under the influence of communication and experience. Thus with non-formal concepts it seems obvious that learning is a personal matter. Formal concepts, however, look so prefabricated, so much like fish from the can, that teachers turn into salespersons almost automatically. And students turn into clients, getting no advice, much less help, in setting up their own breeding factory. Which in turn is bad for the teacher who gets no response. The sea becomes dead, you can smell the salt in the air.

Now we can have p-prims for dessert, as I promised long ago when I mentioned Andrea diSessa's paper "Phenomenology and the Evolution of Intuition". To ask for the students' primitive concepts means to make them start on their own breeding grounds with their own fish and breeding techniques. Gradually they will correlate their experience with yours, and will learn this way. Or of course, they might not; teaching and learning happens by chance, you can only try to raise the chances and the gains.

Prototyping is fundamental in concept formation I maintained earlier in discussing the findings of Eleanor Rosch and others. We need concepts to formulate our experience, and from concepts already known we build up new ones (called 'abstract') through talking. But the human mind does not sustain a long chain of verbal constructions. Rather our way to a new concept is bordered by remnants of battles bitterly fought and of exhiliarating victories, by traces of connections drawn and broken, by semi-sweet or sour-sharp memories. When we use a familiar concept, we leap this path in a single bound; it has become a “form”. But when we investigate the concept, we have to travel the path, see the ruins, smell the fragrant air.

This is even more true, although even less appreciated, for formal concepts. We need formal concepts to deal with machines, and from those already known we build up new ones through long chains of formal definitions. Thus as ordinary abstract concepts get their meaning through verbal descriptions, formal concepts get it prescribed through sets of rules. But we are unable to really follow formal rules for any length of time. Thus as in the informal case, to become familiar with abstract concepts we have to breed them on our own grounds. Starting small-scale, on familiar terrain, and then stepping up, that is prototyping, seems to be the best way to do it. This summer I will give the logic course a finer structure by concentrating each week on a concept pertinent to the respective project exercise. Maybe I can get the students write on their p-prims, making up for the missing weekly exercises.

It is a common complaint that science students will not, and cannot, write. Of course they cannot, if you do not make them write. William Zinsser in his book “Writing to Learn” [1988] describes how much fun it is to write about a theme if one wants to learn about it. (Heinrich von Kleist said the same about talking; see above. Closer to the point Elaine Maimon et al. in “Writing in the Arts and Sciences” [1981] and Paul Conolly and Teresa Vilardi in “The Role of Writing in Learning Mathematics and Science” [1988] write about the same theme.) But this works only if you write about something that you want to learn, or that bothers or frustrates you, that is, that relates to you emotionally. How can students learn that if their only experience is reading papers that contain nothing but facts, where the authors hide behind propped-up results guarded by abstract word monsters? Writing to learn works only in small systems.

We have an old dog who never learned to watch for cars when crossing the street. He may accidentally look into the direction of an oncoming car, but he does not seem to see it. (Now that he is deaf he cannot even hear it.) “Dogs cannot see cars,” a neighbor once explained to me when Bobby again was nearly hit when he ran over to greet her dog. “Living beings move rhythmically; so this is the only kind of movement dogs spot. For them a car does not move. First it is there, and all of a sudden it is here. Bang!” Since then I leash Bobby when I walk him. And I am less rash in teaching mathematics. We all have a long way to go from p-prims which move like natural fish, to formal concepts which move like machines. I have to make the students see the wheels revolve, and the pistons go up and down under the hood, before they will see the car move. It might be that our delight in music and dancing is grounded here: We feel the sheer pleasure of moving moving deep down in our bones and guts.

3.5 A (computer) science utopia

Once upon the time a group of computer scientists met in the castle of Bederkesa in Northern Germany to get a fresh view on their field. Computer science was, not long ago, started by mathematicians and electrical engineers who conceived themselves as dealing with computing on electronic devices. The tasks thus were technical and mathematical; the mathematicians provided the theory, the electrical engineers, the practice. By now this view was grossly outdated. Computers are used in organizing work environments and administrations, in navigating spaceships and designing cars, in regulating the flow of money and providing data to support decisions, and – perhaps by most people – in writing and printing texts and playing games. Thus the really urgent problems were no longer mathematical and technical, but on the basic human level of behavior and social relations, of learning and understanding, of trusting and acting responsibly. What good is the next machine generation or the latest mathematical achievement, if people cannot make use of it, since they idolize or bedevil formalisms and machines, which are, as they know or feel, constructed for inherent reasons and not for the people's sake. Most computer scientists, if they consider the dilemma at all, shove the task over to other fields. They produce machines and formalisms; psychologists and social scientists, philosophers and linguists are there to take care of the consequences. At the crossroads one grows a fig tree, called "computers and society". But the problems won't go away. They well up in each part of the computer science yard, and are not to be dammed up by outsiders nor covered up by fig leaves.

Thus, the people at the Bederkesa meeting agreed, computer scientists would have to cooperate closely with scientits from other fields. But how? The other scientists are not expected to learn computer science, and computer scientists are not likely to swarm out into other fields. Today's universities call for interdisciplinary work, but rarely allow it except in the form thin personal threads. The Institute for Cognitive Studies at the University of California at Berkeley, where I wrote this report, is a striking exeption.

The volume "Sichtweisen der Informatik", edited by Wolfgang Coy et al. [1992], contains (in German) some of the analyses and proposals worked out at the Bederkesa meeting. In one of my contributions, "Sinn im Formalen?", which contains some of the ideas of the present report, I mention a minor incident. On the last evening of the meeting two women and a man sat in a small room in the highest tower of the castle exhausted. It was a dark and stormy night, and they came up with an utopia: From now on all computer science projects are done with participants from philosophy and psychology, linguists and education, social science and if necessary other fields, and always with "ordinary people", potential users and outsiders. To be sure projects would become immensely expensive and annoyingly slow that way, if not outright impossible. But this would slow down rationalization, and thereby curb the cancerous growth of big industry, agro-business, and mega-administration. Hopefully also more of the soft- and hardware actually produced would be usable, and even socially useful. That in turn would help to lower the overall costs. (Just think how expensive an error in a military computer system can be!) Philosophers, say, and other "superfluous" people could be paid out of the project instead from unemployment benefits. And most important, these projects and the resulting products would be more fun for everybody, which would result in healthier minds and bodies. Of course such projects would not turn into small systems automatically. Communication would be very difficult. Here prototyping would be of value, since it induces people to talk. And all fields involved would be influenced positively, not just computer science itself. In all fields big systems could give way to smaller ones. We would work more responsibly.

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